Collaboration-Based Learning Environments Using Augmented Reality

by

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Submitted to the Department of Creative Technologies
in fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

at the

AUCKLAND UNIVERSITY OF TECHNOLOGY

December 2025

ABSTRACT

This research project is an exploration of the use of Augmented Reality (AR) for Collaborative Learning (CL). Current literature shows a growing interest in the use of interactive technologies for teaching and the overall impact of Technology Enhanced Learning (TEL) projects experimenting with the implementation of AR. This technology offers interesting visualisation tools to merge digital information with the physical context of the user, creating unique interactive experiences and boosting engagement for the students, but it had been tested mostly on single-user settings.

The proposal of this thesis is that the unique visualisation capabilities of AR and the connectivity offered by the mobile hardware often used for its deployment can provide an advantage for effective CL. For this purpose, *WorkshopAR* was developed following a user-centred design and implemented within the context of a project-based course in construction design. This application offers the students different tools to help them structure and manage their collaborative work.

The Industry Project course was used as a case study to observe the impact that the introduction of *WorkshopAR* produced in the behaviour of the students during their classroom activities. The main objective was to promote positive changes through the application, helping the students develop and apply important skills for effective collaboration and for a successful development of their project. The risks and uncertainties of such a strong intervention with technology in social, collaborative activities were also taken into consideration, and the observation process also identified negative or undesirable changes in behaviour that could be acknowledged through the iterative development process used.

The case study also offered an opportunity to document the design and implementation of the software. The development process integrated the functional requirements of the tool with the learning goals of the course and tied the iterative development with what was observed in the classroom. This allowed a flexible and adaptable design that boosted the interesting approaches that students and teaching staff were proposing while also helped in redesign those elements that were promoting problematic behaviours.

The results obtained showed that students benefited the most with a strong sense of structure when initially establishing relationships with the group, and appreciated more flexible activities once the work dynamics were clearly defined and producing results. The visual and interactive elements proposed by *WorkshopAR* helped the students understand and be aware of the need of those structures, promoting discussions and guiding work using more impactful collaborative approaches, but failed to integrated in a more substantial way in the workflows that students had already created using a variety of other tools that were better integrated into each other. *WorkshopAR* was able to pivot when aspects of its design were promoting behaviours that were not in line with the learning goals of the course or the research, and several opportunities in the creation of collaborative spaces and communication mediated by AR can be worked upon in future research.

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Acknowledgments

Thanks for all the support and patience of my supervisors, Stefan and Jairo, for their counsel and for going several steps beyond to offer help and oportunities during my stay here in NZ.

Thanks to all the people at the Creative Technologies workshop for all their help. Thanks to Lucky and his support during the data processing of the literature review.

Thanks to COLFUTURO for their financial support and for making this whole process possible in the first place.

To my family, specially my mother, for their support, patience, and for surviving the ordeal.

All ethical considerations Approved by the Auckland University of Technology Ethics Committee on 02/09/2024 AUTEC Reference number 24/230

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List of Acronyms

VR Virtual Reality

AR Augmented Reality

TEL Technology Enhanced Learning

MR Mixed Reality

CSCW Computer Software for Cooperative Work

CL Collaborative Learning

CoP Community of Practice

VLE Virtual Learning Environment

LMS Learning Management System

BRT Bloom's Revised Taxonomy

SLR Systematic Literature Review

CR Critical Realism

AUT Auckland University of Technology

AE Architectural Engineer

CE Construction Engineer

CM Construction Manager

QS Quantity Surveyor

BYOD Bring Your Own Device

TA Teaching Assistant

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor used artificial intelligence tools or generative artificial intelligence tools (unless it is clearly stated, and referenced, along with the purpose of use), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Sebastian Gil Parga

5 of December, 2025

Chapter 1

Introduction

In the Netflix animated series *Cyberpunk: Edgerunners* (Imaishi et al., 2022), the main character attends courses at a prestigious academy that uses advanced technology to boost education and performance. The students gather in a room with Virtual Reality (VR) headsets and connect to the lesson, which is taught by a holographic (and probably powered by artificial intelligence) tutor. The episode does not show the lesson itself (the entire system fails catastrophically when attacked by malware), but the brief scene highlights the vision many people have of a futuristic classroom, one guided by advanced technology and automatization.

Forsler et al. (2024) propose the term "post-digital classroom" to identify the characteristics and trends in education present in a world beyond the adoption of digital technologies. The purpose of this classroom is not anymore to introduce new technologies to students, but to implement them as an essential factor of the learning process. The post-digital classroom is interconnected, social and global. In this scenario, learning goes beyond the physical classroom because it is based on creating relationships between concepts and developing valuable skills rather than acquiring knowledge. It is also a classroom where information is detached from the physical learning institute, and access to facts and sources is, ideally, immediate, ubiquitous and democratic.

The classroom has also become hybrid. There is little distinction between network-based lessons and the face-to-face spaces associated with schools and universities (Goodyear et al., 2004). Hybrid and blended approaches blur the distinctions between learning in an online setting and learning in a classroom. In both instances, information is at hand in the network, students can easily connect to peers and mentors, distance and time constrains are less meaningful and knowledge is presented in a multimedia format (Rivoltella, 2008; Shank, 2005).

This thesis explores the use of technology in such post-digital classrooms, specifically, Augmented Reality (AR) within the context of mobile computing. Moreover, this research will analyse the creation of effective learning spaces, those places where students can build, personalise and control all the activities they engage with (Gourlay & Oliver, 2016). Learning spaces are interesting tools at the disposal of students because these are spaces that can exist outside the norm of a typical classroom, they are more fluid, less structured and can easily connect to other similar spaces (Nørgård & Hilli, 2022). The proposal of this research is that AR can be used to boost the way students build and interact with their own learning spaces.

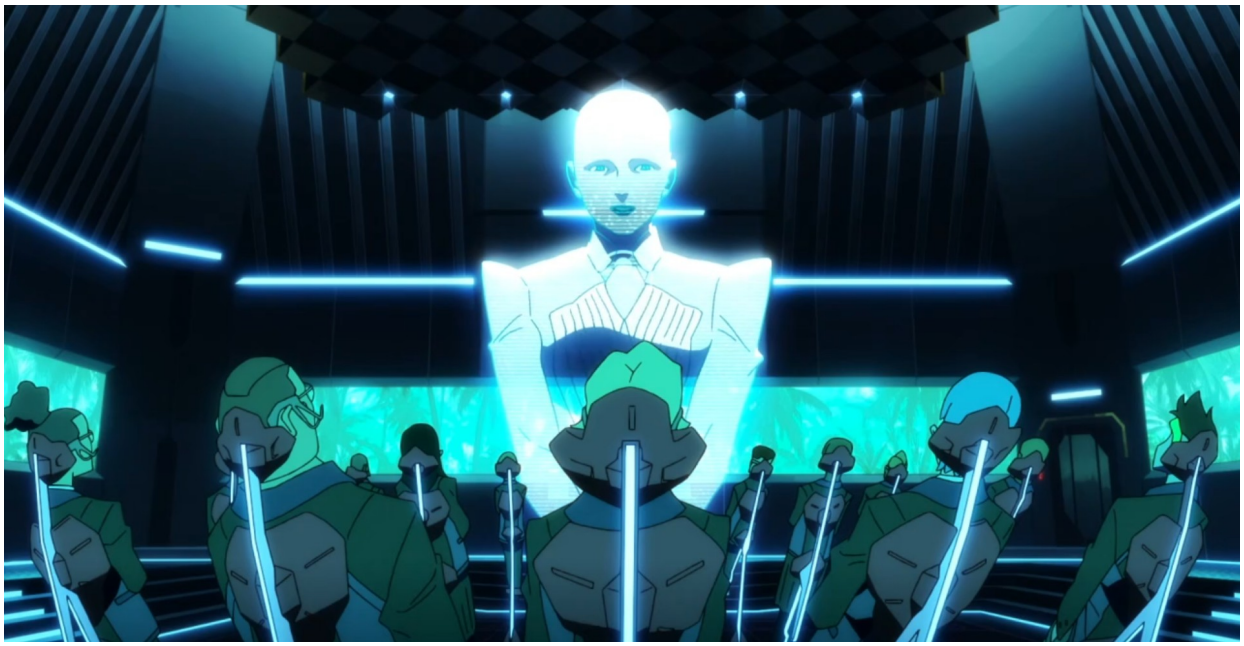


Figure 1.1: Virtual Classroom in Cyberpunk: Edgerunners

Within the field of Technology Enhanced Learning (TEL), AR and related technologies were chosen as a focus of interest because of their intrinsic relationship with space. The initial example scene of Cyberpunk: Edgerunners serves to illustrate the collective idea of what could be achieved in the future with technologies like VR and AR: the possibility of creating an entire new space, suited for the needs of the classroom or the students. It is a space that is shared, in which information and interactions flow between users and that can be controlled at will by students and teachers. In reality, the technology is not quite there yet, especially in terms of fidelity and immersion (Checa & Bustillo, 2020; Hamad & Jia, 2022). What can be explored right now is the creation of interesting synthetic environments that facilitate experiences that are not possible in the common classroom. This process is limited more by the creativity and expertise of the developer rather than by the technology, and therefore can be explored easier and in more detail.

AR, compared to VR, has a more direct relationship with the *real*, physical space and with the context of the user. Instead of an isolated immersion, AR creates a connection with the environment based on image detection, data and visualizations. This natural expression of the technology is where the value of AR can be explored in relation to the creation of innovative learning spaces. The technology not only has interesting capabilities for visualization and interaction, but it also allows an easier implementation of shared, social components that can be used to build activities based on cooperation, shared knowledge and the creation of communities, all crucial elements for the construction of effective learning spaces (Bligh & Crook, 2017).

The research is positioned then in the conjunction of these three fields: Learning spaces, TEL and AR. The guiding goal is to understand how students are using technology to learn, and how AR can be used to boost that process. AR shines at creating immersive experiences that can be shared with others and that consider the physical context of the user. I want to

use this collaborative space as an educational tool that takes advantage of the inherent social aspects of learning.

A personal learning space can incorporate different software tools, many of which are now ubiquitous and almost indispensable in any learning activity: text processors, multimedia editing tools, web browsers and document readers, plus any specialised tool that the learning subject requires. But that learning space is also built around more elements, some of them equally indispensable for some students. People need a space to work, access to different amenities, access to textbooks, information and teachers. Some may need a quite space to concentrate, or, on the contrary, may need access to music, to snacks or to a separate place to periodically take a break. The construction of a learning space involves many different elements, some more technological than others, and its effectiveness is based more on the integration of those elements than anything else (J. Lu & Churchill, 2013; Reinius et al., 2021). This research aims at identifying how to properly integrate AR in the construction of a learning space, which is already composed by a complex web of many other objects, tools and circumstances.

As a researcher. I have explored in the past the way different technologies can be used as part of those learning spaces, either with tools for online learning scenarios or using VR to create a digital space to explore multimedia content (Gil Parga, 2015). This thesis expands on the work done before, identifying ways to adapt a different technology, to apply lessons learned and to explore new avenues of research. In particular, it is an opportunity to expand from personalized learning environments into social learning spaces, and explore the role of the community in teaching and learning.

Some notable literature like Richards (2023) and Long and Ehrmann (2005) shows that the construction of learning spaces is always mediated by the community around us, even when creating a space as personal as possible. Even nowadays that we live in a post-pandemic world where we seek remote, personalised and secure ways of learning, it has become clear that the social aspect of learning is a crucial element in the equation (Baber, 2021; De Felice et al., 2023). The aim of this research is to delve deeper into the social elements that influence the construction of a learning space, how the students negotiate the process of learning with others and the benefits of collaboration, as well as the challenges it conveys.

This is also a technological enquiry. Having explored VR in the past, it was clear that this family of technologies offer interesting advantages by using complex visuals, new forms of presenting information and more natural interactions suited for the exploration and experimentation with 3D spaces. These technologies also present curious challenges, especially in the usability front. For instance, the public has not yet developed a strong relation or consistent literacy with the technology (Özgen et al., 2021), which creates accessibility problems. And those technologies that leverage common and accessible platforms, like mobile devices, risk carrying with them problems associated with the excessive and pervasive presence of such technologies (Forsler & Guyard, 2025; Petrucco, 2021).

The following introductory chapter will expand this brief exploration of the context and motivation for the research proposed, outlining the main research goal and the reasoning behind the formulation of the selected research questions. There will be a brief exposition of the methodology followed to build possible answers, the significance of this research and why the answers to the questions proposed can provide important insights about the way we use technology to learn and how we design technological tools for the classroom. It will be

followed by a summary of the results obtained and the contributions achieved, as well as the scope and limitations of the work done. The chapter will conclude with a description of the structure of this thesis document.

1.1 Context

AR technologies are positioned somewhere in the middle of the reality-simulation spectrum proposed by Milgram et al. (1995), a model for display technologies used to show digital or physical data in virtual or synthetic realities. The main characteristic of AR in this spectrum is the incorporation of the real world as part of the experience, making use of different image recognition and composition techniques to identify features in the physical space and overlay them with digital information.

Schmalstieg (2016) adds another layer of analysis to the description of AR-like technologies by using the ubiquitous computing spectrum proposed by Weiser (1991). The model positions different implementations of AR depending on the use of more static or more mobile deployment platforms. In one end of the spectrum are applications that can only be used in singular static terminals, while the other side contemplate platform-independent mobile technologies and ubiquitous systems. Figure 1.2 shows examples of this distribution as proposed by the authors.

No matter what label is used to describe atechnology, some agreed upon characteristics must be present for it to be categorized as AR, as stated by Azuma (1997):

- A combination of real space and digital information.
- Interaction with the simulation in real time.
- The simulation is done in a 3D space.

Based on the themes introduced in the opening statement of the chapter, the goal is to analyse AR as CSCW. For this task, a useful analytical tool is the classification of CSCW technologies proposed by Rodden (1991) in terms of the point in time and space where the collaboration is taking place. Figure 1.3 shows examples of different systems that can be found in each quadrant of the classification, which indicate whether the activity is synchronous or asynchronous, remote or co-located.

Complementarily, Kiyokawa et al. (2002) offer two important elements present in a collaborative activity: communication and tasks spaces. In the communication space, people exchange information and can sustain formal and informal conversations. In the task space, the actual cooperative work is done. Those spaces can be unified or separated, and they can be physical, virtual or in a mixed state. Independent of the nature of each individual space, both need to be present for collaboration to succeed.

Based on these classification models, it is possible to define the main field of interest of this research as the use of AR in a mixed task space for face-to-face collaborative learning, which implies synchronous activities in a co-located space. In this setting it should be possible to use the capabilities of AR for visualization and interaction with the physical space to *augment* the collaboration process in terms of:

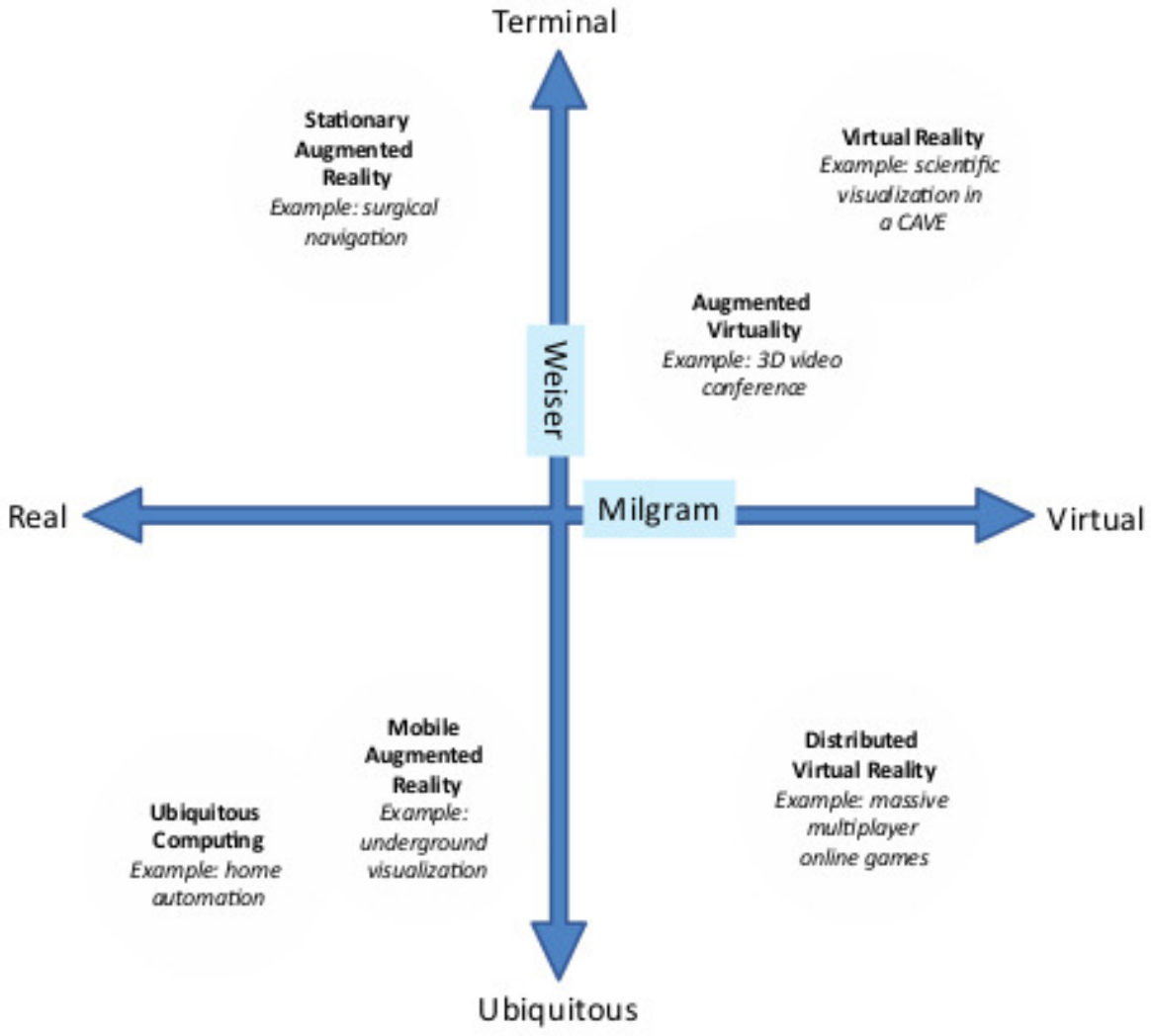


Figure 1.2: AR in the Milgram-Weiser Spectrum (Schmalstieg, 2016).

- Activities related to the communication space, the flow of information and the creation of knowledge in the group.
- The use of the physical space as an asset in the collaborative process.
- Management of the collaborative process itself and the structures that can be created to facilitate effective teamwork and cooperation.
- Guidelines to acquire and refine skills related to teamwork and collaboration.

The main proposal is that the unique characteristics that AR provides in the field of Mixed Reality (MR) are well suited to experiences in co-located collaboration, and that a learning design that is using a collaborative approach can benefit from an AR tool mediating in the communication and tasks spaces of the activity.

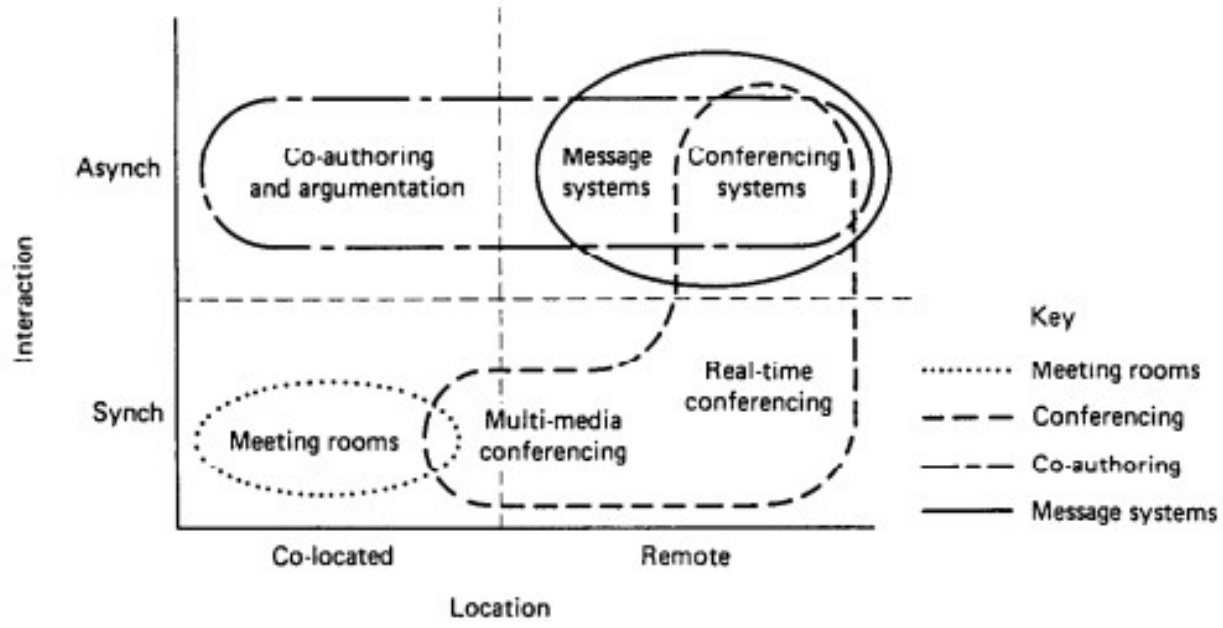


Figure 1.3: Classification of CSCW Systems by Rodden (1991).

The interest in collaborative learning derives from the analysis of the use of AR in education and the tendencies identified in the available literature. It was possible to note that AR is often used as a tool to explore concepts and practices in hands-on approaches that apply previous knowledge in different situations and contexts. Unfortunately, the technology is seldom used in cooperative scenarios, despite the tendency to use mobile platforms for deployment (Gil Parga et al., 2023).

Collaborative learning is a subject rich in discussion. The conversation can focus on the benefits of groupwork in the classroom like promoting different points of view, facilitating complex understanding of a topic and creating the space for an integral development of the student (K. A. Smith et al., 1992; Van Wyk & Haffejee, 2017). On the other hand, the challenges associated with collaborative work are also amply explored (Baloche & Brody, 2017; Buchs et al., 2017; Popov et al., 2012), and there is plenty discussion around issues related to classroom management, inclusivity, effective assessment and good practices.

Many studies have identified and compiled the advantages of using AR and MR as learning tools. For instance, Penn and Ramnarain (2023) offer an analysis of the educational foundations used to design learning interventions. They conclude that most projects converged into constructivist foundations and embodiment theory, opting to create spaces for students to experience and explore the learning subject, with an emphasis on immersion, practice and hands-on interactions. Despite these commonalities, the authors also remarked that most reports do not mention explicitly or do not rationalize the theoretical background of the intervention. They also note that a lot of researchers still hold the idea that introducing a new technology in the classroom is enough to reap its benefits, without caring to build or follow a proper integration plan.

This issue acquires even more relevance now that the mediation of different technologies in the collaboration process has grown due to the Covid-19 pandemic, which forced a quick and

often poorly planned implementation of remote learning (Drueke et al., 2021; Nuere et al., 2021). Over time, this prompted the re-design and re-thinking of how to use technology to support the sudden disruption in learning methodologies and approaches (Adi Badiozaman et al., 2020; Fischer et al., 2020). The forced isolation also highlighted the importance of social spaces in the construction of learning environments, and the need to provide those social interactions even in online spaces (McInnerney & Roberts, 2004; Walas-Trębacz et al., 2025). There is value in the physical space for the learning process (Paechter & Maier, 2010; Petchamé et al., 2021; Thai et al., 2020), and a technology that is able to connect the physical and the digital is worthy of a deeper exploration to identify proper approaches and successful use cases.

The idea is not to oversimplify the presence of digital technologies in the classroom, nor follow a misguided tendency of selling all the benefits of a technology without acknowledging its problems. If the proposal is to identify the effects of a collaborative learning design mediated by AR, it is important to also identify all the problems that derive from this approach, either because of the issues that naturally come from teamworking scenarios in the classroom or the negative behaviours that the excessive use of digital technologies promotes, especially in the specific environment of mobile platforms.

With that context just detailed, it is possible to summarize the goal of this research as: The construction of an AR tool that serves as aid in a collaborative learning setting by helping students to communicate and develop teamworking skills. This can be achieved by means of interactivity, visualization, immersion and augmentation of the physical space.

1.2 Research Structure

The goal of the research can be justified by an abundance of literature showing the elements of AR used in the past to offer distinctive value for learning, and the open opportunities to explore and understand better the development of multi-user AR experiences for collaboration. The nature of the proposal implies that the research has two main fronts:

- In the *technological* front, the goal is to build a software solution that considers the development challenges of an AR tool in a multi-user and multi-platform environment, and the specific requirements derived from the learning goals proposed in the educational front.

- In the *educational* front, the goal is to identify, describe and develop a case study based on collaborative learning, and to analyse the behaviours that students develop when learning in a collaborative environment mediated by technology, comparing the use of AR with other tools or approaches.

1.2.1 Research Questions

The guiding research questions of this project are aimed at obtaining information of what constitutes an effective collaborative learning design using AR. The answers can be stated in terms of learning goals, interaction design and integration plans with the classroom. The questions also seek information about how AR is creating an effect in the behaviour of the

students while using the tool for learning. These behaviours can be related to communication, socialization, planning and engagement with the learning material. The main research question will be stated as follows:

> MQ: How does the behaviour of a group of students changes when using an AR tool designed to aid in the achievement of a learning goal framed in a collaborative learning scenario?

To guide the implementation of the tool through a strong design, a lot of information can be extracted from current literature and from previous projects using similar approaches. Information gathered from real and incremental usage off the system also offers valuable insights in terms of usability, viability and end-user perception. With this in mind, an iterative development process is proposed to facilitate the exploration of ideas regarding interaction design and a proper fit to the learning scenario where the tool is going to be used.

The implementation of the tool alone is insufficient to answer the main question. For this purpose, a case study research methodology is proposed with the objective of identifying and describing a strong context in which collaboration is used for learning and in which the implementation of the AR tool can be contrasted and compared to other approaches. In this context it is also easier to observe more natural behaviours from the students and the observations will show results closer to how the tool could be used in a real deployment.

A set of secondary question can be described that will help to focus the data gathering stages of the research, especially those related to the observations and activities in the context of the case study:

> SQ1: What differences in behaviour can be observed between students collaborating using the AR tool and those that are not?
>
> SQ2: What differences the students report in their perception of the activities done in the course between those using the AR tool and those who are not?
>
> SQ3: How does the collaboration and communication process changes between students using the AR tool and those that are not?
>
> SQ4: What differences can be observed in the end results of the course between all the different collaborative approaches observed, especially of those that incorporate the AR tool?

The focus of the observation process should be in identifying behaviours and processes rather than only differences in the end results, that is, the final assessment of the course project. Relying solely on possible improvements to grades or assessments can be a valid but flawed tool to understand the effects of a technology in the classroom (Dalziel, 1998; Katz et al., 2017). Additionally, the selected case study proposes a complex course to analyse, where several and diverse factors influence the work of the students. Taking this into consideration is why a positive or negative result does not tell the full story and why is more important to observe the whole learning process, from planning to development, documenting the behaviours developed to fulfil tasks and reach goals. The objective is to identify if the AR

tool proposed is an influence, either positive or negative, and if it provides a more meaningful impact to the learning process as a whole and not only to the end assessments.

Assuming there are actual substantial differences between the students using the AR tool and those that are not, then it is also important to ask:

> SQ5: What elements of a technological intervention using AR create the most impact in changing the behaviours, perceptions or results of the students?
>
> SQ6: What elements of a multi-user AR tool creates the most impact in changing the behaviours, perceptions or results of students collaborating and communicating in a learning scenario?

These last questions are meant to provide an evaluation to the decisions taken in the development of the AR tool, especially the multi-user interactions, and how the tool was integrated to the learning design of the course. It also offers the possibility to highlight elements of the tool that could be polished or reframed in future work.

1.2.2 Proposed Development and Intervention

The core of this proposal is in a software development using AR aimed at creating a tool that facilitates and guides collaborative work in the classroom. The tool is meant to help in the creation of collaborative skills such as task planning, role management, resource allocation, decision making and communication.

A university-level course was selected to contextualise the tool within a real classroom with concrete learning objectives. This intervention is used as a case study to observe the effects of the AR implementation in the development of collaborative skills and as a new technological tool for the students to use as support for the development of their project and learning experience.

The following subsections will briefly describe *WorkshopAR*, the AR tool developed, and the Industry Project course, the selected case study.

WorkshopAR

This thesis will document the design and documentation of *WorkshopAR*, and AR educational tool designed to facilitate collaborative work for the development of an architectural design in the context of the Industry Project course. The tool provides a set of modules that provide a structured approach to common situations of team management and decision making in a group of students and which are independent of the particularities of the course:

- A set of tools for identifying the members of the team, their roles during the work session and the space used for the team to work, both physical and digital.
- Tools used to organise and to give a tangible presence to the debates and ideas of the group, and to augment the process of communication in activities like provide feedback, discuss options or propose solutions to a problem.

Additionally, *WorkshopAR* provides features related specifically to the learning objectives present in the Industry Project course, aimed primarily at helping in the ideation and design phases of the architectural design project. These tools consist of a set of digital objects that could be manipulated in the digital space to aid in discussions about architectural design, construction problems, spatial design, among others.

WorkshopAR followed an agile development methodology and a user-centred design focused on iterating over the experiences of users around interactions with the tool, the development of their project and the real usage of the software in the classroom. The design and development of *WorkshopAR* is described in chapters 4 and 5.

Industry Project Course

It is very important to carefully select a case study that not only offers unique circumstances valuable enough to be analysed in detail but also has the proper learning context to explore the themes of interest of this research project. Although the specific learning field of a prospective case study is not that important, it needs certain characteristics, independently if it is developed through a single activity, a section of a course or through the whole course. The case study must incorporate all the following elements:

- A clear learning goal, either as a whole or as a step to achieve a more complex goal. Assessment activities alone are not enough because the research objectives require the observation of collaborative learning, not the development of a single teamwork activity.
- A collaborative approach to the learning activity. Students must be expected to work in groups to achieve the task, or at least, to have access to a space for collaboration in the development of the activity, even if it is individual in nature.

Given these limitations, the Industry Project course opens the possibility to observe a learning design completely based on collaborative work, aimed at developing teamwork skills, to contextualize and put into practice theoretical knowledge and to build a solution based on the input of different disciplines and professional profiles.

The course was developed across 22 academic weeks and allowed for the implementation and intervention with *WorkshopAR* around the student's work in their projects, observing the initial consolidation of their teams, the design proposal of the solution and the work done to finalise and present the project. Four groups of students were observed in a combination of activities with and without the use of *WorkshopAR*, and the accumulation of those observations form the main corpus of data for the development of the case study.

Additionally, extra data related to in-class activities, assessments, non-academical interactions between students and interviews with teaching staff complemented the observations to create a wide view of the course, how the students approached the academical challenges presented by the project and how *WorkshopAR* influenced, positively and negatively, their approach and the interactions with each other.

The selection of the Industry Project course also had its drawbacks and limitations. It was possible to only observe one cohort of the course, following the same group of students through the development of the project, which poses a huge limitation on the variety of the

observations and skews the data into the specific approaches and situations present with the students during that cohort.

The course also lacked any form of actual teaching material and was focused entirely on the development of the project, which offered an interesting opportunity to observe collaborative work, but limited the initial proposal to use collaborative learning in the construction of knowledge. A more complete analysis of the scope and limitations of the case study will be explored in the next section and expanded in Chapter 3. The full development of the case study is present in Chapter 6.

1.2.3 Scope and Limitations

Using a case study methodology, it is possible to approach the research questions through a qualitative lens, which is better suited for understanding the information gathered about behaviours, relationships developed between students and their subjective perceptions of the course, the activities developed, and the results obtained. All those elements would be hard or contra productive to try and quantify. In this light, it is important to acknowledge the limitations in scope and reach derived by the selected methodologies.

In relation to the software development aspect, it is important to establish the scope of the product as a prototype that explores the ideas of collaboration and multi-user AR. A thorough analysis of the design and architecture of the software was conducted to describe different possible approaches and solutions suited to the context and the needs of the tool, keeping an analytical mindset for all the ramifications and consequences derived from the implementation of a particular idea or design.

In terms of the concrete implementation of the software, the work was undertaken by a sole developer and limited in time and resources related to access to the case study. Most of the design and architectural proposals were tested via mock-ups or wireframe prototypes (Coleman & Goodwin, 2017; Sutipitakwong & Jamsri, 2020) in pseudo-structured test scenarios, aiming primarily for quick feedback and impressions rather than structured data. This allowed constant iteration and exploration of different ideas. The final implementation of the software prioritized showing the most critical use cases and the most relevant interactions with the tool, most of them tailored for specific observation sessions.

This approach had an important influence in the structure of the observation process and the nature of the data gathered, fomenting a more guided use of the tool and a more structured response from the participants rather than the free observation initially intended. This was an acceptable concession made to facilitate the development process and to give the participants early and consistent access to the tool, albeit in a more incomplete state. This also minimized the disruption to academic work while maximizing the opportunities for meaningful observation in the available time.

There is also an inherent problem in the development of a case study in relation to the applicability of the results, generalization and subjectivity. The Industry Project course was chosen because it fulfilled all the characteristics needed for the research, but convenience aside, the course also provides a unique opportunity to analyse a collaborative learning design in action, with scenarios that could be extrapolated to other similar contexts, but also a unique take on the design of project-based learning and assessment, as well as a complex context for implementation and challenges that had to be tackled, all elements worth of a

detailed analysis.

Nonetheless, it is important to identify the limitations of using one sole case study, which can be summarized as issues with the transferability and applicability of the data gathered. Other factors that impact heavily the nature of the data are the overall seniority of the students, which were all close to finish their studies and the lack of a concrete study plan of the course, which focused more on the development of the project as its main teaching instrument, offering just a relatively vague and general set of learning goals.

Chapter 3 will describe in more detail the scope and limitations of the case study, as well as the measures taken to minimize or acknowledge the flaws and restrictions of the chosen framework. For now, these issues can be summarized the main limitations related to focusing the software development into a gradual an iterative progression of a prototype and the validity of the case study in terms of the characteristics needed for the research and the unique value it offers for analysis and discussion.

1.3 Significance and Contributions

The technological environment in which we found ourselves right now evolves rapidly and at large steps. Despite critics of stagnation, the classroom evolves and adapts in response and constantly tries to understand how the available technologies can improve the way we learn (Watters, 2021). It is not always a positive relationship, it is often marred by overselling products and forcing a technological implementation without a plan and a proper consideration of the context and needs of the classroom (Cochrane, 2012; Odunaike et al., 2013). Currently, it is also a field that experiences a lot of social scrutiny as we react to the idea that we have become somewhat addicted to digital content and to the devices used to consume it (Gui & Büchi, 2021; Liu et al., 2022).In a context in which we are banning the use of smartphones in the classrooms and obtaining somewhat positive results because of it (Rahali et al., 2024), why, then, rely on a proposal that fundamentally uses that technology?

As Murray and Perez (2014) establish, exposure to technology does not equal comprehension. In an age in which almost all aspects of life are mediate by digital activities, it is important to create a positive, critical and informed relationship with the technology that we have to use in our daily lives, and that relationship does not develops naturally (Margaryan et al., 2011; Selwyn, 2009). This is a task that can and should be executed in the classroom at different levels of schooling, in different contexts and at appropriate age and field depths. The classroom is the ideal scenario to create and nourish this relationship in a structured and positive way, yet this is a factor that is seen as lacking in education institutes, especially in middle and high school (Burton et al., 2015; Jeffrey et al., 2011).

This project is an exploration of that philosophy, and an experimentation with a technological design that uses mobile devices in a healthy approach that promotes the development of skills needed today. Although the capacities of AR as a learning tool are evident, this endeavour needs to follow a due process. It is important to properly understand how to use the technology and what elements of the design and implementation process need to be highlighted and worked on to create that intended positive impact. The technology does offer a big opportunity to enhance and reframe the way we communicate and work together, but it also has proven to impose certain challenges that have to be analysed, understood and

dealt with.

This document will describe the proposal, design, implementation, observation and analysis activities done in the development of an AR tool for collaborative learning and the test deployment conducted focused on developing skills related to teamwork and effective communication. The development of this research was carried in two interlocked steps. In one hand is the design and implementation of the software *WorkshopAR*, an AR tool used as a companion in the face-to-face work that was part of the activities proposed for the Industry Project course. Specifically, the software was used during the weekly group sessions of work that the students held for the development of three different assessment milestones in the course-long project.

The development of *WorkshopAR* consisted in solving two main issues, both related to the technological front of the research. First, there was a design challenge that required identifying the most common interactions performed in an AR environment for cooperative work. Different use cases were identified that were unique for this context and that posed an interesting design challenge, like sharing information, sharing and coordinating resources, managing the status of the team and coordinating the development of a task. A user-centred interaction design process was used to outlined solutions for the identified use cases based on important restrictions and particularities of the problem.

This stage was accomplished through a detailed exercise of user-centred design, a process meant to identify ideas and decisions born from the direct interactions of the users with prototypes and mock-ups, a structured process for gathering feedback, integrating the user in the design loop and refining ideas in an iterative process. The results obtained highlighted interesting issues and ideas related to multi-platform interactions, the expectation of users when presented with familiar and unfamiliar controls, complications related to interactions in a 3D space and the integration of the tool in the overall workflow of the students.

The second focus in the development of *WorkshopAR* was the technical challenge of creating a multi-user, shared AR space. Several commercially available frameworks and APIs were explored, such as the AR Foundation suite provided by the Unity game engine and the Lightship API provided by Niantic. It was possible to extract valuable insights about the current state of the development of AR tools, especially in the field of education, and it was possible to describe the lessons learned while integrating the development process with the educational goals of the course. An effort was made to relate the results obtained to those reported in similar studies by identifying common and divergent results and issues, especially those related to finding the technology distracting and the technical development of the tool too detached from the role of the educator.

Parallel to the construction of *WorkshopAR* was the development of the case study and the design of the intervention of the Industry Project course. In the design phase, the course was analysed based on the written material available and on interviews with the teaching staff. This information was used to guide the development of *WorkshopAR* and to identify the instances in the progression of the course in which the intervention could create more impact without disrupting too much the academic activities of the students. It was also an opportunity to detail and analyse the learning design of the course and to understand the context in which the observations were going to take place.

During the observation phase it was possible to obtain detailed observations of the work done by the students with and without the AR tool, about the development of the project

through the conception, design and implementation phases, to adapt elements of the tool to better suit the circumstances of the course and to observe the role of the teaching staff in the development of the course and as part of the usage of the tool. This helped to create a rich record to report in the case study and plenty points of analysis and discussion.

The analysis phase used the recorded information from the observation stage plus all the material that could be recollected from the execution of the course. This material included the written communication given to the students via the official channels of the course, the workshops executed during the semester as material to help in the development of the project and the final products created by the students, such as presentations, reports and designs. The observations were also complemented by a set of semi-structured interviews to the students and the teaching staff. The interviews focused on gathering better records of issues related to the personal perceptions about the use of technology and the collaborative activities of the course.

From the observations obtained and the analysis of the results it was possible to formulate some possible and satisfactory answers to the research questions. The data points to interesting behaviours promoted by the intervention, such as students creating a more structured work process when the tool prompted or encourage them to do it. It was also observed that this enforced structure helped the students with the organization of activities, prompting good practices for communication and the organization of ideas and plans.

But the structure also prompted some unintended behaviours, like a tendency to create a hierarchical organization of the group around the student managing the tool, which was not in tune with the objectives of the course. The app also forced the students to be aware of their phones more than they were planning or willing to do, highlighting a current trend among students of regulating their phone consumption. It was also noticed that the tool was most useful for teams struggling with their organization and offered little value for those already with a clear work plan.

Data and observations also provided a lot of insights related to the design of collaborative interactions in virtual 3D environments, to the relationships of students with their phones and how students use different resources, properly or not, to sort out the difficulties of a learning project. It was evident that the social aspect of the collaborative work resonated the most with the students and with the general satisfaction they reported with the activity, giving more importance to the tools created for them to communicate, express ideas and personalize their experience. The case study also opened an unexpected opportunity to analyse the role of the teaching team in the use of the tool, offering a clear path for future work.

1.4 Document Structure

The purpose of this document is to provide an organized recount of the development of this research work, the theoretical background that supported the proposals given and the methodology followed to gather data, analyse it and build a set of answers for the research questions.

This introduction chapter was meant as a summary of all these elements, highlighting the personal motivations behind the chosen research field and the general reasoning that accompanied the design process, the hypothesized and desired results, as well as the methodological

pathway taken. Chapter 2 of this document will describe in detail the literature explored that helped in shaping the research questions and that provided the theoretical basis for the educational methods used as anchors for the software implementation.

Chapter 3 details the methodological framework of the research. It briefly explores the research paradigms picked to guide this project and explains the reasoning for choosing them and their relevance to the learning and technical fields this project is based on. The chapter will also offer a complete explanation of the educational front, detailing all the instruments used in the development of the case study. In the technical front, it details the software development methodology followed, especially the reasoning and procedures used for the interaction design process and the methods used to ensure usability, flexibility, expandability and a general user-centred approach.

The description and analysis of the results have been divided in three chapters. The technological front has been described in Chapter 4, where a detailed explanation of the requirement analysis can be found, including use case scenarios and quality objectives. The chapter also details the most relevant elements of the architectural solutions proposed for the tool. Chapter 5 continues with the description of *WorkshopAR*, now focused on the implementation process followed. The chapter describes the design phase to the development cycles followed to build the software, the testing strategies used to ensure validity and the feedback received by the users during testing and the observations in the case study.

The case study itself is described in Chapter 6, explaining the context of the Industry Project course, the teaching objectives guiding its design and the points of interest for the intervention using *WorkshopAR*. The chapter will also provide a narrative description of the observations taken over 20 weeks of development of the course, and a preliminary analysis of the data based on the secondary material extracted, like the written documentation, the work produced by the students and the information gathered from the interviews.

The final analysis is presented in Chapter 7 along with the necessary conclusions gathered from the data and the process described in the previous chapters. The chapter will detail what elements of the development of *WorkshopAR* and the case study support the proposal of AR as a tool to promote positive learning behaviours and effective collaboration, what important technological hurdles were identified and what surprises were found during the development of the project. The chapter will also offer and outline for future work to address the most outstanding issues derived from the research limitations and the problems encountered during the development of the project.

Chapter 2

Literature Review

This project is centred around the concept of Collaborative Learning (CL): the process of acquiring or creating knowledge as part of a group, and the dynamics that emerge when a team needs to manage participation, the overall success of an activity and the learning objectives that need to be fulfilled (Laal & Ghodsi, 2012). It is also possible to analyse the concept as learning to collaborate, to acquire the skills needed to be an effective team member.

The purpose of this literature review is to find the benefits of adopting a CL approach in a learning design and the challenges that any educator needs to consider when implementing a strong focus on collaboration. It is also important to understand why collaboration and teamwork are such important skills to develop, why is it so valued in most professional environments and why is there a general feeling that educative institutions are failing in teaching those skills.

The lens of analysis will be Technology Enhanced Learning (TEL): the use of technologies to support processes or management of teaching and learning (Passey, 2019). A narrower focus is set on Augmented Reality (AR) technologies. The objective will be to understand how AR can be used in the classroom, and the particularities that it offers in terms of benefits, challenges, common implementations and relevant success stories.

AR can be a valuable collaborative learning tool based on the unique abilities it possesses. Specifically, the technology excels at incorporating strong visuals into the surroundings of the user(s), which provides an opportunity to design enticing experiences for both learning and collaboration. For this purpose, it is important to identify what collaborative experiences have been created in the past with AR, what learning goals align with the technology and what challenges in design and development can be expected.

This chapter explores these questions and themes across three sections. The first section tackles the topic of collaboration, how it is defined and measured, different implementations in the classroom, perceived benefits, common challenges and lessons learned from previous projects. The second section presents a systematic literature review aimed at identifying the use of AR as a tool for education, how the technology has evolved, which elements of the technology have derived in success stories, and which have become challenges. The final section will combine both subjects and explore the literature for previous experiences using collaborative AR, both in education and in other fields.

2.1 Collaborative Learning

2.1.1 Collaboration as a Transversal Skill

The subject of CL is wide and can be tackled through different angles. For instance, we can talk about collaboration as an isolated term, and relate it to similar concepts like teamwork, cooperation and intrapersonal skills. In need of a definition, the approach taken by Andriessen and Baker (2020) is very complete. The authors state that "(...) collaboration means developing, in an equal and mutually respectful way, a shared view of a situation". Is a simple definition that implies two important things. First, collaborators find themselves in equal terms, there is a sense of equality and mutual correspondence. Authoritative or hierarchical relations hardly produce collaborative settings. Second, collaboration goes beyond cooperation, beyond working together to fulfil a goal. Collaboration implies building, through time, a shared view. The group has a shared set of goals, purpose and values. The classical definition of collaboration proposed by Roschelle and Teasley (1995) also complements this idea by stating that cooperation involves the division of labour among participants, of individual responsibility, while collaboration is a coordinated effort to solve the problem. Echoing this distinction between collaboration and similar ideas like cooperation or teamwork, Salmons (2019) states that collaboration is a process that needs to constantly be managed, while teamwork is a more *natural* or *improvised* way of working together when needed.

Andriessen and Baker (2020) later expand all these ideas by stating how collaboration is built through time in three different dimensions. In a personal sense, we collaborate because we gain something from it, or because we need to do it. Our goals align with those of others, creating a second inter-personal dimension, in which we also care about the relationship we create with others and the social advantages we obtain from the collaboration. Finally, with strong inter-personal interactions, we create a group dynamic, in which decisions are taken beyond the individual level and align with the necessities of the group. This evolution can be fractal, which means that after a strong group has been created, it can be developed in a fourth dimension, an inter-group relationship in which several tight-knitted groups collaborate in a shared purpose within a bigger system.

Now is possible to build an initial definition to be use as conceptual backbone. Collaboration will be understood as: the process in which a group of people build a set of values, shared views and coordinated efforts to fulfil a purpose or reach a goal. This definition considers the most important aspects highlighted previously by other authors: collaboration goes beyond just coordinating tasks because is strongly linked to building relationships and communities, therefore, it is a very social skill. Collaboration is not a single action, is a process that needs time and effort to be constructed. Finally, collaboration is aimed, it needs a purpose or a goal. More important, that goal needs to be shared among the collaborators instead of being imposed. Collaboration can only be developed when all the members of the group find themselves as equals and share the perceived value or the necessity of working towards that aim.

It is possible to add more elements to the definition, creating a wider and stronger framework, if we analyse the concept of collaboration from other perspectives. For instance, collaboration can be viewed as a skill to be acquired within the context of professional development and employability.

As stated by Crant (2000), it is common for a workspace to seek in a professional a proper balance between theory and knowledge, that is, the information gathered through practice and experience. This position can be read as employers seeking people that have built a career rather than only have a profession. Additionally, employers seek candidates that can properly response to a variable environment, either due to high pressure or a fast-moving market. Employees must then demonstrate personal adaptability, a willingness to explore, and life-long learning values. Finally, employers seek for the ability to properly construct and use the surrounding social context, the employee needs to build social capital by cultivating abilities in cooperation, networking and teamwork.

This framework shows the importance on adding value to the professional profile, and highlights skills related to adaptability and collaboration as key value pointers. The framework also relates easily to other popular concepts like social intelligence, personal development and problem-solving attitudes, all part of what has been known as transversal skills. The UNESCO defines transversal skills as those that can be used in a wide variety of situations and work settings (UNESCO, 2014) and are valuable for their general applicability and transferability. These skills can be organized in five broad categories:

- Critical and innovative thinking.
- Interpersonal skills.
- Intrapersonal skills.
- Global citizenship.
- Media and information literacy.

To understand better the type of abilities that the previous categories encompass, we can extract some ideas from diverse sources in the literature, a small set of studies focused in understanding the work market in different contextual variations of geography, professional field, years of experience and even nature of the job-hunting process (Abir et al., 2024; Boahin & Hofman, 2013; Garst et al., 2019; Huynh et al., 2024; Llorens et al., 2017; Nadarajah, 2021; Ng et al., 2021; Smaldone et al., 2022; Zhang et al., 2024). This sample of literature shows the type of skills most demanded by employers around the world. Although skills that are considered *hard*, or better described as field-specific are understandably diverse, there is almost a complete coordination related to *soft*, transversal skills. These skills are common to all contexts and independent of the region or work field. Figure 2.1 shows a visual distribution of the most common transversal skills sough after in potential candidates, extracted from the studies mentioned above.

Despite being a small sample, the data shows a clear emphasis on relational skills, and it seems to portray the added value of hiring and developing people with high communication abilities, teamwork, good social interactions, and flexibility (Al Asefer & Zainal Abidin, 2021).

Another important sentiment that can be extracted from all the literature mentioned is a perceived discordance between the skills and abilities focused on by high educational organisations and those sought after by companies and employees, as identified so far in this section (Damoah et al., 2021; Ng et al., 2021).

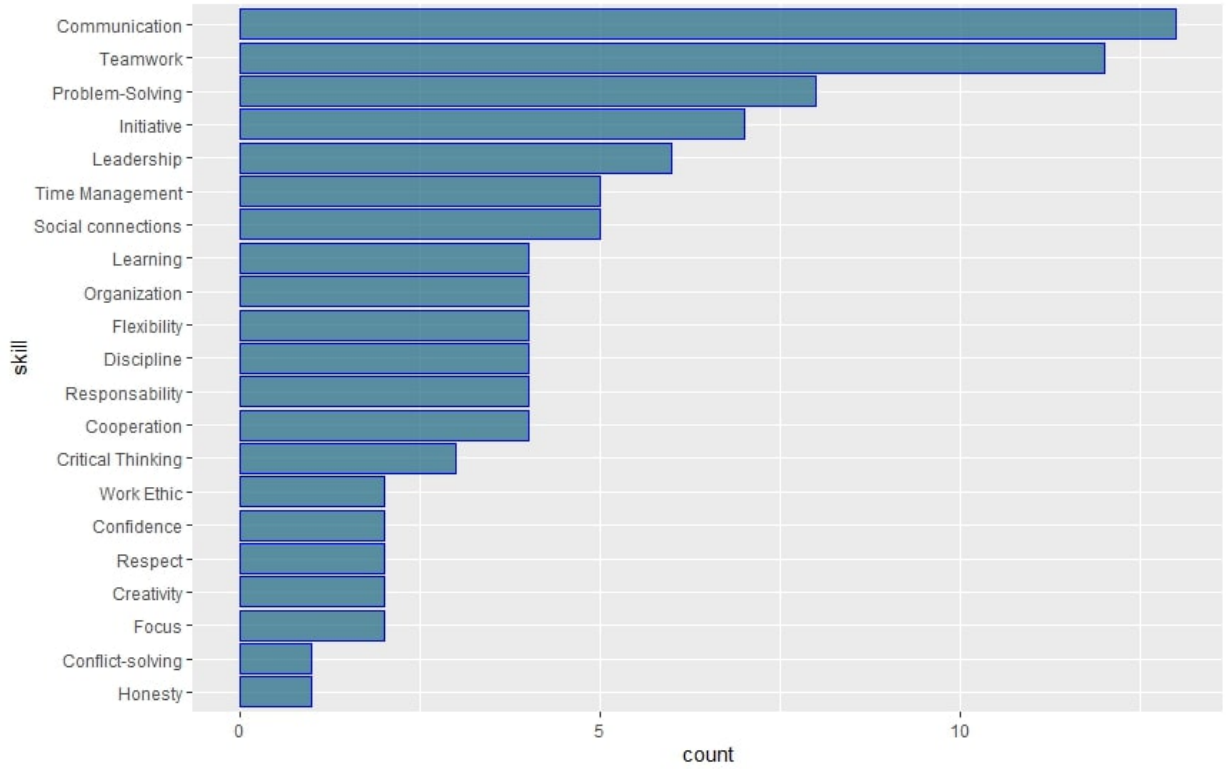


Figure 2.1: Most Common Soft Skills Identified

Tulgan (2023) identifies specifically three soft skills missing in young workers: professionalism, critical thinking and teamwork. Tulgan argues that this gap is closely related to a generational and technological shift where there is a lower need to develop communication skills because we have offloaded most of our communicational needs into electronical devices (mails, meetings, conversation, social interactions), forgoing the opportunity to develop such skills in person.

Tulgan keeps explaining that in recent years *good old-fashioned* teamwork became an issue for young people, who have developed a different set of values that clash with those of previous generations. Where older generations built a long career as part of a company or institution, newer generations have little to no loyalty to a single employer, and they are more likely to search for better deals. Young professionals find little value in adapting to the ways and established institutions of a group when they know very well, they won't be there for too long.

Secondary and tertiary education programs are often seen as the main responsible agents in the development of skills deemed crucial for the general professional life (Kechagias, 2011) and is in this light that modern curricula in almost all disciplines now have a higher emphasis on building those transferable skills (Earl et al., 2021). This is not without problems, and there is a noticeable consensus that teaching such skills is not a trivial task (McCale, 2008). Several factors influence the ability of a curriculum to provide such learning pathways. Most common problems are related to how little educators are prepared to incorporate those skills in their classrooms (Kemp & Seagraves, 1995), the costs of adapting the curriculum, training

the personnel and changing old mindsets to effectively provide the space to create such learning (Chadha, 2006).

Considering these extra contextual elements, it is possible to modify the previous definition of collaboration as follows: Collaboration is the skill to work as part of a group by identifying, building and acting upon a set of values, shared views and coordinated efforts to fulfil a purpose or reach a goal. This modified definition not only states a set of characteristics of what the process of collaborating implies, it frames it as a skill to be executed by each member of a group, and not as something that happens naturally when people gather. It also acknowledges the need to learn and develop such skills.

2.1.2 Communities of Practice

A term proposed by Lave and Wenger (1991), a Community of Practice (CoP) can be defined as a set of mechanisms of situated learning used by communities to transmit knowledge internally, especially to newer members. These communities are formed around a focused domain and were initially used to describe the learning process used in different trades like craftmanship and health practices. The meaning of the term has been broadening with time and can be applicable to any group that gathers towards a common goal over an extended period, that is, enough time for several generations of members to come and go.

Strongly linked to CoP is the idea of legitimate peripheral participation. This can be defined as the process in which newcomers learn mostly through observation and gradual participation with their senior peers (McDonald & Cater-Steel, 2017). CoP are used to give some structure to the process of informal learning, especially the type of learning found outside of academy, and which is more linked to professional practice, personal development and the relationships forged in the day-to-day activities with peers and a community in general.

A healthy CoP is one that is generated naturally due to the interaction of a community around a specific domain. It is different from a task force or team of people gathered around a goal or a problem in the sense that the general objective of a CoP is more undefined in terms of time, is focused more on the practice rather than the goal or product itself and is constituted by a social community rather than by just a collaborating team of people. These are the three fundamental elements that define a CoP: a domain, a community and a established practice, as described in Figure 2.2.

The domain is the knowledge base in which the community chooses to work because it offers value or just interest in general. New members come voluntarily and interact with elder members gaining experience in the practice, with the expectation of eventually gaining mastery.

The community is a group of people that can be driven by complex social dynamics. The community will create norms, stratifications and behaviours over time. The community is expected to be in a constant flux of members and to evolve with time, in terms of social interactions and the relationship it has with the domain.

The practice is an integrated set of activities and knowledge executed and transmitted by the community to create mastery over them. Some CoP focus more on nurturing members into the mastery of the practice, while other focus more on the transmission and preservation of the knowledge generated, as noted by Klein et al. (2005).

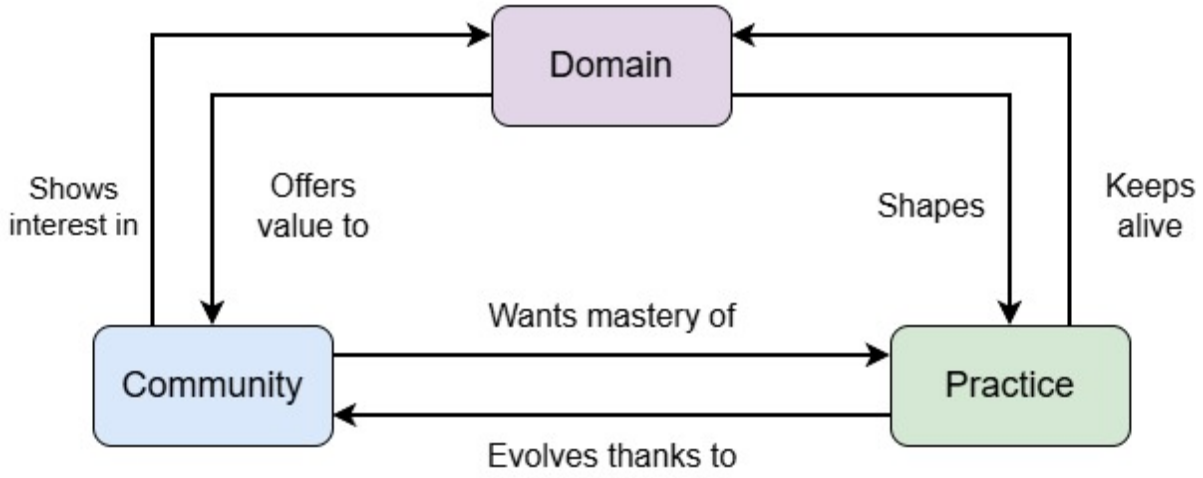


Figure 2.2: Elements of a Community of Practice

CoP have shown to be the cornerstones in the development of informal and social learning, leadership development and organizational change (C. Anderson & McCune, 2013). Often, high indexes of performance and employee satisfaction are present when a CoP has been identified and nurtured within the informal structure of an organization (Blackmore et al., 2010). Also, they have proven to be valuable integration, communication, and identity reinforcement tools in communities with a high degree of disparity or diversity among members (Hildreth & Kimble, 2004).

A particular emphasis on the idea of nurturing a CoP is important. A community can perish due to lack of proper nourishment or caused by artificial intervention. Previously it was noted that it is not possible to force the creation of a CoP, new members must voluntarily engage in legitimate ways with the practice. But even when a community develops and grows in members, and its value is acknowledged and sough after, forced practices that run in contradiction with the spirit of a CoP can end up killing it. Authors like Ardichvili et al. (2003) and Brown and Duguid (1991) have analysed the lifecycles of successful and failed CoP inside the organizational practice of many and varied industries, from insurance brokers to high education institutes. Of all the key factors identified in the failure or disappearance of a CoP, it is useful to highlight the following ones:

- Not allowing enough time for members of the community to form relationships and sustain them. This can be due to frequent administrative reorganization or the prevalence of temporary or part-time staff.

- A culture of tight management, where every aspect of the practice is highly standardized and supervised, and there is no possibility for a natural development of the practice due to the relationships formed in the community.

- A culture of highly individualized work, either due to the very nature of the practice or because of other factors, like a very competitive environment. This inhibits collaboration and discourages collective engagement.

- Practices with extreme time or performance pressures, which leaves little time to develop a collective or communicative environment.
- Spatially fragmented work, so that there is no opportunity to establish a relationship, or because there is not a common, unsupervised space for the community to gather.
- Communication and activities are heavily mediated by technology or even other people. This makes interactions (arguably) less immediate and intense, therefore, lacking importance.

So far, all the elements that have been illustrated paint the concept of a CoP as a natural-occurring social structure formed around the need of preserving, communicating and nourishing knowledge within a well established community. It is a manifestation of informal education that thrives and offers the best results when acknowledged at an organizational level but not tampered with (Brown & Duguid, 1991), and when given enough resources to grow and evolve (Klein & Connell, 2008).

Given the importance of naturality and informality within the definition of a CoP, it is possible to see how these fundamental elements can be at odds with the expectations and common practices found in more traditional and institutionalized education, where learning is more structured, participation is hardly voluntary and collaborative processes are more task-focused rather than long-term approaches to the practice. These issues will be acknowledged in the following section.

2.1.3 Communities of Practice and Education

A common image of what could be considered *collaborative learning* in a classroom setting can be of a group of students working together to fulfil an assignment, say, a presentation on an assigned topic. Although it is possible to define this group of students as a community that came together with the goal of learning something, it fails several other criteria needed to be called a CoP.

In first instance, the example scenario breaks the idea of *natural occurrence*. The group was not formed by the voluntary interest of the students to engage with the domain, but as a necessity to complete a particular task. Also, it would not be uncommon for the composition of the group to be a forced assignment, either by chance or by the designation of the teacher, which would not constitute a community formed by the natural connection of its members.

The community itself also lacks perpetuity because its existence is linked only to the fulfilment of the task. Although the students can benefit from the work done alongside their peers, the knowledge and mastery acquired benefit only the immediate members of the group, they will not be transmitted to other members, nor is it expected for the group to grow and evolve.

Despite all these short comings, there are advantages in using the CoP approach in this scenario. For example, it can be argued that the activity does offer a genuine peripheral participation with the practice, allowing the students to engage with elements of the domain and work towards mastery. This engagement is achieved more through structured lessons rather than by informal observation of the actual practice, but it still offers the general idea of a gradual and guided approach.

To properly identify the community formed around this practice more elements need to be added to the analysis. In that way, the natural structures that are normally present in a CoP will get clearer. By including the teacher in the community, it is possible to identify expected elements like eldership and meaningful learning-focused forms of communication. By considering all the groups formed by all the students in the classroom, not only the initial single group, it is easier to see the opportunities for more meaningful relationships to be formed between peers, for more variations on the ways they approach the task or for more opportunities for that practice to evolve. The same results can be obtained by extending the timeframe in which we are analysing this activity, and considering not only the current cohort of students, but also all previous and future groups that participated and will participate in the activity. It is possible to keep adding more elements to the scenario, like all the teachers that have overseen this course and all the courses that are part of the same department, for instance. This exercise exemplifies that, although there are fundamental problems in the definition of a CoP in the scenario of institutionalized education, a lot of the core elements can be found with interesting variations.

A study group could be a better example of using a CoP as a useful framework of analysis in this context. In these circumstances, it is common for the group to form naturally, as a voluntary activity surging from the necessity of mastering a subject (for an upcoming test, i.e.) or because the students have identified that having the support of other peers helps them achieve better academical results. In any case, the core purpose of the group is learning and practice, rather than the fulfilment of tasks. The relationships between the participants extend beyond organizational roles and the focus lays on the transmission and collaborative generation of knowledge and expertise.

Cremers et al. (2008) analyse the formation of CoP in higher education in a similar way to the one proposed before. They argue that knowledge sharing and knowledge creation require a different set of skills than those needed for groupwork. A CoP becomes an ideal tool to promote those skills and to prepare students for the type of informal learning processes they will find later in life. Yet, forcing students to create a CoP or creating a lesson around the use of a CoP goes in contradiction to the spirit of the term, which is meant to be voluntary and informal. A study group work the best when the students themselves want to be part of it.

It is then necessary to come back to the idea that a CoP must be cultivated rather than created (Wenger et al., 2002). When designing a lesson, a course or a curriculum, several steps can be taken to promote the natural formation of CoP. Klein and Connell (2008) propose a series of principles used to nourish CoP that can be followed to create proper spaces for them to form naturally. For example, students should be allowed to propose and develop their own activities, with possibilities to grown on their own and to have active channels of communications with external sources, like teaching staff . It is also important for students to have access to physical spaces to develop such activities, encouraging both public and private work. The teaching staff should also be aware that they are stakeholders in this scenario, being an integral part of the *value* that the students create by engaging with the CoP and the natural *rhythm* the creation of this CoP follow related to the activities proposed by teachers, like due dates and exam weeks.

Cremers et al. (2008) go a step beyond and propose that students should actively learn to be part of a CoP, arguing that it is no different to learning the proper skills to be a good team member. Speaking in terms of learning outcomes, they establish that a student should

be able to:

- Reflect on the state of the practice and the necessities for future development and evolution.
- Be able to communicate and make explicit the results of their engagement with the practice.
- Be able to use the resources of the community in their engagement of the practice.
- Construct, organize and create new knowledge in collaboration with the community.

Rather than asking students to create a real CoP or forcing their participation in one, there is more value in giving the students the tools to understand the dynamics found in a CoP and the proper way of participating and creating value in one. Keay and O'Mahony (2016) echoes this idea by arguing that the significance of a CoP lies in the process rather than in the product. The process of interacting and collaborating with the community has an inherent value, even if a CoP is not properly constructed, and that is what a student needs to learn and be exposed to.

It has been noted by several authors that the dynamics found in a CoP can also emerge and be fostered in online environments, such as Riverin and Stacey (2008) in the perspective of the students and Kirschner and Lai (2007) in the perspective of the educators. These online CoP can emerge and be effective provided that similar circumstances allow the natural growth of the community, like an open participation and clear opportunities for mentorship. CoP for online environments have been found to boost participation and engagement in students, especially young ones (Thomas, 2005), which reinforced the idea that the creation of a community is crucial for a successful remote learning experience (Archambault et al., 2022; Swan, 2002), which circles back to the importance and usefulness of collaboration as a learning tool.

In summary, a Community of Practice is an analytical framework better used to understand processes of informal learning strongly linked to the social dynamics of its members (Wenger, 1998). These characteristics often find themselves at odds with the more formal and structured forms of learning in educational institutions but still offer valuable insights and working tools when analysing the activities done by students outside the structure of a classroom, and more related to their practice of being students.

As discussed in Section 2.1.1, collaboration is as skill that needs to be developed, not only because it is a well sough-after *soft skill*, but also because it is an integral component of professional development, community integration and life-long learning skills. As students, we become part of a particular Community of Practice that works around the development of useful skills for learning and academical success. The development of these skills is, at risk of proposing a circular definition, a collaborative process, one that is hard and unproductive to create in a forced or artificial manner, but than can be promoted and grown given the proper resources and the correct nourishment.

2.1.4 Learning Teamwork and Collaboration

A lot of literature can be found that try to create a model of how individuals come together as a group to achieve a goal, identifying all the factors (internal, external, personal, emotional or circumstantial) that contribute to the success and failure of a group. For example, Bion (2003) offers a good explanation of the Tavistock approach, a systematic view of the psychological dynamics present in the conformation and life cycle of a group. This model identifies important structures that appear inside a group like authority figures, responsibilities, boundaries (both internal and external), crisis responses and organizational structures. Participants form and engage with these elements even if they do not properly identify and name them.

A group can also be analysed in terms of the behaviours adopted by its members. Bales (1970) categorizes the possible interactions performed by team members into task-oriented and emotional. The latter category can be charged with a positive, neutral or negative tone. These behaviours can be expressed through every form of communication that the group uses, including non-verbal cues like body posture or voice tone.

Following the behavioural line of thought, E. S. Knowles (1982) identifies some factors that strongly influence the unique identity that a group develops through time. Factors like time constraints, physical environments, group size, composition, overall goals, patterns of participation, communication tools and the set of norms, procedures and structures that emerged within the group.

All these elements create a valuable toolbox of concepts that are useful to systematically describe the work, behaviours, relationships and experiences of a group. They create an essential common language that describes problems within a group, propose solutions, set goals or creates awareness of the elements that are expected to emerge or the issues that must be addressed when working with others. These elements shouldn't be the focus in the process of teaching collaboration but do offer a solid structure in the design of a solution.

A better approach to the learning process is to understand why we collaborate, not only in terms of the employability necessity that has been exposed previously, but also in terms of finding value in teamworking, even if the approach was not voluntary or when collaboration becomes a necessity rather than a goal. When framing our group relationships through the idea of creating value for the group and extracting value for ourselves, we can focus on identifying all the aspects that develop an effective collaboration, those that create more value (DAWSON, 2017; Wagner et al., 2010). When identified, these factors can be replicated and taught in controlled and varied scenarios so that students become aware of their value, build their own experiences of success and failure in a safe space and gain proficiency in identifying and replicating those same elements by themselves.

Hibbert and Huxham (2005) use the terms collaborative advantage and collaborative inertia. We navigate towards collaboration because we find a tangible advantage in the process (for example, the task cannot be accomplished by an individual). But even with a concrete advantage, no interaction can be initiated if the initial collaborative inertia is not surmounted. This inertia is defined as all the barriers that impede collaboration, things like:

- A personal unwillingness to seek input or to learn from others.
- Hoarding expertise, defined as an unwillingness to help others, share knowledge or skills.

- Inability, due to lack of skills or resources, to transfer knowledge.
- An impulse to compete.

The role of competition, especially in academic settings, has an interesting antagonistic nature to collaboration. A dose of competitive elements in an academical setting creates interesting results in terms of providing motivation and building a sense of belonging (Bergin, 2016). Yet, it has also been analysed that focusing too much on the competitive aspects of schooling can derive in undermining the intrinsic value of learning (Tauer & Harackiewicz, 2004) or creating an environment in which the competition is more important than the learning outcomes (Kowalski & Christensen, 2019). This pervasive sense of competition in schools is one of the main issues behind the generalize reticence of students to participate in collaborative activities, which can also derive in lack of motivation, loss of focus and general disinterest in the goal of the collaborative activity itself (Driscoll, 2025; Kloepper, 2023).

One of the first steps to implement a framework for learning how to collaborate is to identify which of these barriers are at play and provide tools to deal with them and not just hope for people to continuously stumble into these problems and finding solutions by chance or by trial and error. Salmons (2019) provides an extensive analysis of what collaboration is and how to create an environment that teaches and promotes it. One first effort is to acknowledge and identify different types of collaboration, defined by the overall achievements gained and the value obtained by participating in the collaboration. Salmons identifies these four degrees of collaboration:

- *Co-creation:* Collaborative generation of new knowledge, processes or products.
- *Acquisition:* A team effort to acquire or develop new skills or knowledge that none of the participants had prior to the collaboration.
- *Transfer:* Sharing expertise or knowledge between the members of a group to create a wider and more complex pool of knowledge or skills.
- *Exchange:* Sharing physical and human resources to fulfil a goal that could not be achieved individually.

Salmons also offers a complementary approach to the idea of value generation explored in other literature. She establishes that before any form of valuable collaboration can be generated, it is important to reinforce two cohesive elements of any group trying to work together: trust and communication. These building blocks are the main forces used to create meaningful connections inside the group, which in the future leads to the creation and perception of value.

Trust refers to feeling comfortable while working towards and sharing goals with other people. *Trust* can also be seen as a form of social capital (Addison & Teixeira, 2020) that determines how willing is someone to cooperate with others and accept relationships and situations of dependence (Zand, 1972), risk, uncertainty (Frederiksen, 2014) and hope for mutual benefit (Kramer & Tyler, 1996). On the other hand, a lack of trust can be evidenced trough feelings of dread and exhaustion within the group, forcing collaboration only when strictly necessary. Vangen and Huxham (2012) also identify the ability to create a safe

environment for all the members of the group as an exercise of trust, where the social risks associated with dealing with other people are negated or mitigated, so it is possible to concentrate in creating results consistently. A group that can create trust within is more resilient to external issues, to errors and to conflicts. It also shows a better capability for self-reflection and faster course correction (Shinya et al., 2016). A high level of trust is also correlated to safe environments for innovation and risk-taking (Bichard, 2005).

The second building block proposed by Salmons is to develop proper channels, skills and habits of communication. The author describes two types of communications in a collaborative setting:

- *Dialogue:* Defined as formal and structural communication best used for planning and coordination. It is also the best form for establishing rules and initiating collaboration itself in new groups.
- *Conversation:* Defined as informal and loose communication used to create relationships. It is also the best tool to build and convey trust in the group.

Proper and structured dialogue is also the main venue for students to learn and practice collaboration. Essential aspects of teamwork can be evidenced and assessed through activities guided by dialogue that students engage with. The structuredness of dialogue also helps in creating activities and resources that show collaborative skills that students can develop and provide evidence of, such as:

- Proper use of interpersonal skills.
- Understanding of the task or project.
- Work design.
- Task allocation.
- Quality assurance.
- Coordination.
- Communication of progress.
- Accountability.
- Conflict resolution.
- Decision making.

With these elements is possible to create a roadmap that guides a lesson, a project or an assessment in which collaboration is an important learning goal.

Through dialogue it is also possible to create a third communication skill fundamental for a successful collaboration, *review*. This is defined as a process of self-reflection focused on the work or progress done by the group. A review process can also be structured, facilitating teaching and assessment activities, and can be mapped, as shown previously with the main indicators of dialogue, to key aspects like:

- Ask and give support.
- Analyse and challenge other's contributions.
- Analysis and incorporate feedback.
- Encourage peers.
- Monitoring peers.

Other authors like Keay (2006) proposes similar criteria for proper collaboration in terms of trust, respect and effective communication. Additionally. example implementations like the one showed by Lingard and Barkataki (2012) highlight some other success factors like developing a sense of self-organization, inclusivity and responsibility. Marasi (2019) proposed a series of activities that highlight important attitudes and approaches for healthy teamwork like listening before responding, being affirmative of other's ideas and being mindful of nonverbal communication. Davis and Ulseth (2013) and Asrori and Tjalla (2020) iterated over these concepts and proposed different frameworks, activities and observations that identified other important ideas like accountability, feedback, ownership, empathy and long-life learning.

Table 2.1 serves as a general summary of the concepts and ideas explored throughout this section and shows a map that links fundamental criteria of effective collaboration with activities and behaviours that acts as helpful evidence of those fundamental elements in the work and interactions of a group of students. This map provides a structured tool that will be used as an initial standpoint for all the educational and technological developments of this research project that have collaboration as the main learning goal. They are also a useful tool to frame the analysis of the work done by student in the development of the case study and to describe the learning design proposed by the Industry Project course.

2.1.5 Conclusion: Approach to Collaborative Learning

Collaborative learning can become a useful tool for the classroom based on the approach taken to encourage and manage teamwork. While trying to collaborate in the fulfilment of a task, students learn how to summarize and share information, co-construct ideas through dialog and debate, and improve retention and comprehension through the simple action of raising questions and answering them (Andrews & Rapp, 2015). Activities requiring teamwork also help in the development of critical thinking abilities (Zandvakili et al., 2019) and prepare students for a realistic work environment (Chowdhury et al., 2002).

Collaborative activities help students create a better understanding of the task at hand. Salmons (2019) uses the concept of *workflow*, where students must discuss, design and implement a concrete plan that help them achieve their objectives. Even if this plan involves a simple coordination of consecutive or parallel tasks, or a more complex synergetic form of work, the process of coming with ideas and solutions to tackle the needs of the task creates a stronger involvement with the team and the project. Similarly, coordinating work efforts develops proficiency in communication, especially in developing literacy (and digital literacy) around tools for remote communication, file sharing, document cocreation and asynchronous work coordination (Lo, 2009; Murphy & Cifuentes, 2001).

Table 2.1: Evidence Factors and Assessment of Collaborative Work

Criteria	Evidence	Examples in Literature
A shared common goal	Work Design	Fisher (2014) and Kernaghan & Cooke (1990)
	Goal and task ownership	Kropp & Dodd (2024) and Sohmen (2015)
	Co-creation and acquisition of knowledge	Drejer & Jørgensen (2005) and Salmons (2019)
Willingness to collaborate	Inclusion of all members	Keay (2006) and Zubiri-Esnaola et al. (2020)
	Affirmation of all ideas	Marasi (2019)
	Group bonding and empathy	Blanco et al. (2017) and Widayati et al. (2022)
	Share knowledge and resources	Nissen et al. (2014)
Proper management	Task allocation	Hirshfield & Chachra (2015)
	Self-Organization of the group	Keay (2006)
	Communication patterns	Amponsah (2003) and Jahng et al. (2010)
	Flexible structure	Gross (1997) and Jacobs (2015)

Collaborative activities are also often associated with creativity and transformative learning by providing the proper conditions to bring ideas together, compare solutions and expose different viewpoints (Peppler & Solomou, 2011; Turnbull et al., 2010). Rubbing ideas together offers extra value to the generation of knowledge by also providing the circumstances to make connections around that knowledge and challenging preconceptions or stereotypes (César & Santos, 2006; Eden & Ayeni, 2024).

But working in a collaborative setting is not without its challenges and hurdles. Just the act of being in a group is not enough to boost the educative process of the students. If the proper tools are not provided and major barriers are not acknowledged, the situation can flip around, and teamwork can become more of a liaison than a boost.

One of the most common issues is power imbalance, a natural occurrence whenever there is a group of people gathered towards a common goal (Essabbar, 2015). Elements related to gender, social status or economic issues, among other things, are always factors to consider when using teamwork as the main driver of a lesson. When a strong imbalance is present in a group, it can be evidenced is several behaviours and outcomes that could hinder the learning process of the students. Different authors have identified some of these patterns in different contexts, like inconsistent exposition to the learning material, coarse relationships forming between students, lack of agency in work distribution (Griffin et al., 2015), stress, downgrading performance and lack of response to feedback (Van Der Vegt et al., 2010).

Educators need to develop the necessary foresight to acknowledge these difficulties and provide the students the tools to solve them. In general, it has been shown that self-reflection, an effective mediation and clear communication methods work the best when dealing with

issues of imbalance. A closely related analysis. A lot of studies have worked on strategies to identify these discrepancies and how to work around them, proposing tools like peer-assessment (Rezaei, 2018) participative rotation, close time management (Davies, 2009) and smart grouping (Akhrif et al., 2019; Q. Wang, 2009).

Management chaos is also always associated with groupwork, not only from the point of view of the students but also from the educators. It is expected that students will have problems with managing elements associated with groupwork, like distribution of work, problem solving and self-reflection. It is also expected that the students will find the educational material needed to learn how to cope with those management issues in the educators or the course itself. Nonetheless, it is surprising how often it is expected that students collaborate without giving them the tools to learn how to do it. Bruffee (1973) provides an interesting record of his experiences implementing a collaborative approach with his students, and a lot of information can be extracted from this case study in terms of the work needed to set-up and manage the tools, environment and mindset that allows a proper collaboration. This extra management time is noted to be present both for the students and for the educator.

Jaques and Salmon (2007) also identify other behaviours that arise when students don't feel comfortable working in groups. Poor participation and general distress can be associated with cultural differences and expectations around how to behave in a group, or, as Biggs et al. (2022) also noted, around personalities that inhibit themselves easily when in a *formal* or *high stakes* form of participation. Other issues reported by students themselves are related to frustration around low performance groups, previous bad experiences or having to deal with personalities that are too outgoing, and which completely dominate the whole group in detriment of other students.

It is important to acknowledge and provide pathways to deal with inevitable issues around conflicts and overhead management time. With all this material is possible to propose a guiding conceptual framework for the educational and technological design that is going to be undertaken in this research. This guideline consists of four principles:

1. Collaboration is a skill that students need to learn and develop. This learning offers value to the employability profile of the student, to the development of lifelong transversal skills and as a useful tool to facilitate more learning.

2. Students develop a form of CoP when learning together, with emerging relationships with their peers, their environment and their learning goals. This communities can be nurtured, which in reciprocity generates a rich, heavily knitted and unique development, both as learners and professionals.

3. It is possible to aim for the ideal characteristics that help the development of collaborative attitudes and use them to design and develop learning tools that take advantage of a collaborative learning approach.

4. The advantages inherent to collaborative learning can be minimized or negated if proper attention is not given to the equally inherent problems that immediately arise. Any learning tool needs to be designed around these issues and provide resources for

both the students and the educators to propose solutions fitted to their context and particularities.

This set of guidelines is meant to inform the design and development of learning objects, tools or experiences.

2.2 Augmented Reality in Technology Enhanced Learning

This section will explore the current use of AR in the education sector to identify advantages, disadvantages, common issues and, in general, the current state of the technology as related to the field of education.

2.2.1 Context

The idea of technology-mediated education has often been linked with that of collaborative learning. Lehtinen et al. (1999) highlight key ideas about the communication process developed in learning scenarios and how we use technology to facilitate and manage such activities. Many of the main concepts explored by the authors echo those already presented in the previous section . Ideas like the importance of nurturing a community, selecting proper tools for communication, structured process of review and mediation are explained in similar detail as before, as well as other common issues identified, like excessive competitiveness and factors for social friction.

Dillenbourg and Fischer (2007) propose some recommendations to incentivise effective collaboration in students, like physical spaces that facilitate interaction instead of individualisation, a common but flexible structure for collaboration that is transmitted to the students and techniques that the educator can use to orchestrate the technology used in classroom. It is key to acknowledge that the process needs constant moderation and motivation to create consistent results. These examples reinforce the idea that collaboration needs an extra effort to transform the work performed by teams into knowledge and learning. Coordination between the technology mediating the interactions and the expertise of the educator building the experience is crucial to achieve that goal.

Complementary, Kirkwood and Price (2014) offer a systematic review which aim is understanding what is being enhanced when talking about TEL. When categorising the data, the authors found that interventions often sought changes in the current state of an educational material, and that the chosen technology could offer positive quantitative or qualitative changes, either in terms of markings, assessments, results, motivation or deeper understanding of the teaching material.

The literature in the realm of TEL is rich and it is possible to identify some form of evolution in the topics analysed when following the jump from teaching machines (Watters, 2021) to computer-aided learning, to online and mobile learning. Among all the information that can be found it is easy to get lost or confused in all the definitions and terminologies proposed. A good example is the term Virtual Learning Environment (VLE), which will often be used to describe the approach of this research. It tends to be used interchangeably

with another concept, Learning Management System (LMS), which refer to the tools used in the administration of educational content and other administrative functions common of educative institutes, which is not the aim of this research. The term VLE is often abused a little to try and give more value to a system or set of tools more akin to an LMS.

To establish more precise use of the term VLE, we can use the characteristics given by Warburton (2009) like immersion, a sense of presence, visualisation, contextualisation of content and simulation of impossible or dangerous experiences. It is interesting that the author also emphasises these elements:

- Tools for affective, empathic and motivational interactions.
- Intelligent interactions between individuals, communities and objects.
- Opportunities for individual and collective identity and role-play.

The emphasis on the social aspects of the interaction with any form of educative technology is crucial when analysing the enhancement provided by the tool in question. That emphasis can be summarized in three important elements: Visualisation of content, sense of presence and immersion, and a sense of collaboration or participation with other people.

With a a more precise definition of a VLE at hand and a set of tools to draw comparisons between technologies, in terms of visualisation, immersion, interaction and collaboration. The next question would be, why focus on AR? What makes AR an interesting technology for education? What makes it special or different enough from other technologies in the same spectrum, like VR?

AR saw a surge of popularity between 2011 to 2013 (Akçayır & Akçayır, 2017; Fidan & Tuncel, 2019) due to many factors like a wider adoption of suitable technologies for deployment. Successful implementation of applications in diverse scenarios has also been documented and reported (Javornik, 2016), and access to developer-focused tools like ARCore and ARToolkit prompted and facilitated development efforts. In general, and very similar to the case of VR some years prior, successful applications and explorative research was boosted thanks to new toolkits and technologies that facilitated learning and development.

In contrast to VR, the resources needed to develop and deploy an AR solution are less complex, and generally cheaper (Ivanova, 2018). This relative ease of development makes AR a popular technology to try out without the risk of committing too many resources into one single solution.

In terms of comparing the usage of AR with other similar technologies, different studies have shown numerous perceived advantages in the use of AR at different levels of education, and they are mostly consistent between studies: enhanced engagement in the learning activity, high levels of immersion and cost efficiency in terms of deployment and usage (Challenor & Ma, 2019; Chen et al., 2017; Saidin et al., 2015).

Common problems found are also consistent throughout literature and they are mostly related to usability issues: technology instability, steep learning curves and time-consuming usage. The term *cognitive overload* is also commonly found through the literature, normally associated to the unnecessary stress derived from the complications of using the technology in addition to the demands already present in the learning activity.

It is noticeable that most reported results are focused on validating the engagement of a particular development rather than its educational role in the learning activity and the educational objectives associated with the project in the first place. To broad the analysis of why AR is a valuable technology for education, a complementary question can be asked: What educational goals are being fulfilled with the use of AR technologies?

The idea behind this question is to identify actual pros and cons of AR technologies through the lens of educational achievements rather than usability or feasibility, as is common in the current literature. To facilitate an answer, four supporting questions can be proposed:

- Are there other advantages or positive outcomes beyond a spike in the student's engagement?
- Are there circumstances in which AR technologies work better than other technologies?
- What are common practices and mistakes emerging from the reviewed literature?
- How do advantages, mistakes and general results change when the field of study or the educational level changes?

Given that AR is the main focus of this research, it was important to propose a deeper review of current literature in order to give substantial answers to the questions just proposed, and to position the technological development of this research in a proper educational basis that both uses well established educational practices and explores avenues, solutions and ideas missing or seldom touched by current literature. Sections 2.2.2 through 2.2.4 will then discuss in detail the systematic literature review performed for this purpose.

2.2.2 Systematic Literature Review Methodology

One common way to analyse learning objectives in any given scenario is by using Bloom's Taxonomy (Bloom et al., 1964). This classification proposes 6 categories in which a learning activity can be positioned depending on the cognitive complexity it requires from students. From easiest to more demanding, these categories are: Remember, Understand, Apply, Analyse, Evaluate and Create. Each category is meant to be seen as actions the students must take to achieve any educational goal.

The taxonomy is a flexible tool in education, useful for both design and evaluation processes. It can be used to understand how a course or lesson is trying to achieve a goal, and if it is doing it with the correct approach (L. W. Anderson & Krathwohl, 2001). It can be seen as the initial blueprint for the design process of any educational material (Healy et al., 2011) and it has also been used as the basis for establishing standards and policies (Guskey, 2001).

Nonetheless, it can be argued that Bloom's taxonomy offers only a one-dimensional approach to education, relegating knowledge of any subject as the simplest aspect of cognition. Krathwohl (2002) proposes a revised taxonomy in which knowledge is a second dimension that gives context to all the other cognitive categories, considering all the ways in which different domains at different levels of education approach learning. This knowledge dimension proposes four categories: Factual, Conceptual, Procedural, and Metacognitive. These categories are

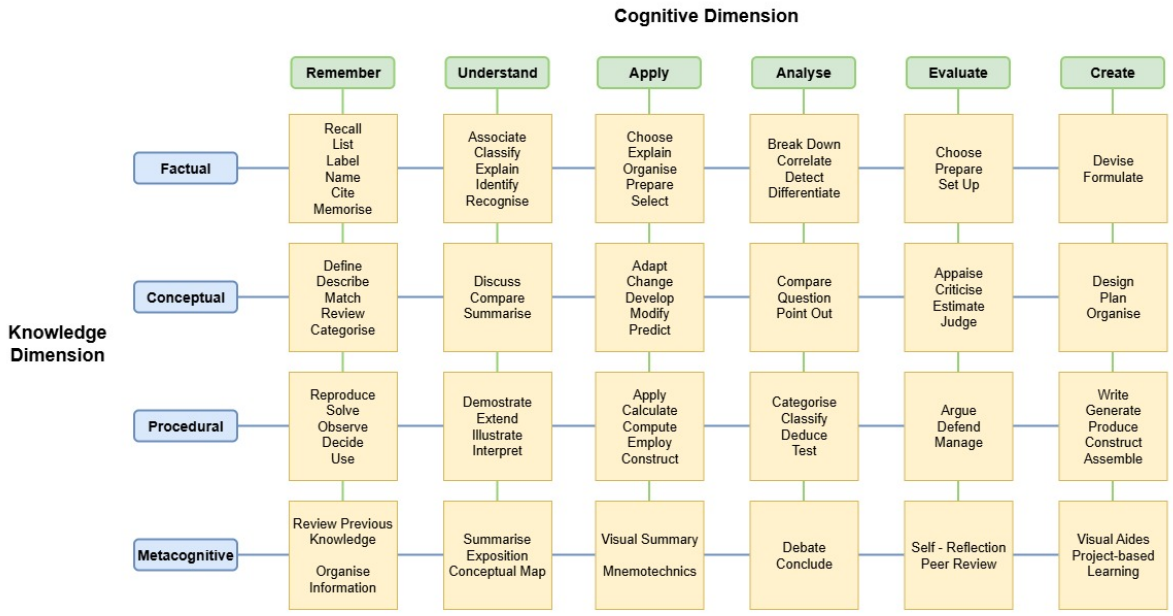


Figure 2.3: Bloom's Revised Taxonomy with Example Verbs

not meant to be hierarchical like in the cognitive dimension, just a representation of the type of knowledge that is acquired. In conjunction, the knowledge and cognitive dimensions can give an educational goal a more pinpoint description of what it is trying to achieve, and a more substantial tool for comparisons.

Figure 2.3 shows a visual representation of the taxonomy as the intersection of the complexity of a task with the type of knowledge that is asking the students to acquire. The figure shows some examples of action verbs that can be used to describe each intersection. These examples were constructed using as reference the works of Newton et al. (2020), Radmehr and Drake (2017), and Stanny (2016), which perform an amazing job at compiling, synthetising and organising reported lists in the literature of common action verbs used at each level.

This visualisation will be used as a reference to analyse the academical material found in the web to determine the pedagogical goals of a particular project. The Bloom's Revised Taxonomy (BRT) framework is valuable because it can offer insights about the complexity of a goal, the nature of its educational setting, and a concise and easy description of the goal itself to use during the analysis of the information gathered.

This SLR process consisted of four distinct phases: selection, filtering, codification, and a final analysis.

Selection Phase

This phase focused on finding relevant work in AR tools for education at different learning levels and fields as possible. The main selection criteria in this phase were the year of publication and the technology used. The timeframe selected was from 2017 to 2021 due to the amount of work already done in the 2011 to 2016 period (Altinpulluk, 2019; Arifin

et al., 2018; Chen et al., 2017). This timeframe also helped to focus the analysis on recent projects with a more contemporary understanding of AR technologies and access to modern development tools and products.

The technology had to be reported as AR in the title, abstract or key words list. The term had not to be exclusive or opposed to VR or MR, this with the purpose of not excluding works that could add valuable information for the analysis prior to a more detailed reading. It is also very common to use the terms AR, VR, and MR interchangeably and are common umbrellas for more specific technologies that could be used to define projects of interest for the SLR.

Google Scholar was the selected search engine using the following queries:

- (augmented reality OR mixed reality OR AR OR MR) AND (education OR training OR learning) AND (technology enhanced OR technology assisted)
- (augmented reality OR mixed reality) AND (education OR training OR application) AND (review OR evaluation OR case study)
- (augmented reality OR mixed reality) AND (industry OR job) AND (training OR instruction OR practice)

Due to the nature of the Google Scholar engine, more than 10000 results were found and could not be realistically managed in a reasonable timeframe. Nonetheless, Google Scholar was maintained as a search engine due to the diversity provided by the tool in comparison to other engines and aggregators. Only the first 10 pages of indexation were used to limit the initial selection of papers. At this point, sources were excluded if any of the following elements were identified in the abstract or summary:

- A merely technical approach to MR technologies with no identifiable educational component.
- A systematic review or a collection of case studies that would make it difficult or impossible to access information about each individual project.
- A duplicate of previously surveyed articles.

Filtering Phase

The amount of literature to be reviewed was reduced to truly relevant material with enough reported information for any analysis to be possible. A first set of criteria was used to exclude projects that:

- Use VR rather than AR or a form of MR that did not fit well into the AR definition, as proposed by Milgram et al. (1995).
- The AR implementation assisted or facilitated a task rather than to educate or train, i.e., surgery planning instead of anatomy education or procedure education.

- Show a general discussion of AR as a tool in education or other context, and not a particular application or case study that could be coded and analysed.

It was possible to identify these elements by quickly surveying sections like the abstract, the introduction or the methodological description. A second set of criteria was used to determine if the project in general provided enough information to process it in the coding phase:

- The article had a clear enough explanation of the tool and its pedagogical purpose.
- The article had a description or discussion of the outcomes of the project or experiment.

For these elements, it was necessary to make a deeper reading of the results, discussion and conclusions sections, and because of that, it was done in parallel with the codification phase.

Codification phase

In this phase, two researchers extracted the relevant information from the selected literature and classified it into two categories:

- *Analytical information:* Year of publication, target demographics, target field, particular AR technology used, success of the project (either reported or inferred) and specific experiences during the development or deployment of the tool. Special attention was given to identifying, if possible, reported positive and negatives outcomes with the tool or its usage.
- *Pedagogical information:* The concrete pedagogical goals of the project as enunciated by the text itself or inferred by the researchers. Educational goals were coded in the format *action verb + statement* as specified by Fuchs and Deno (1982).

Determining whether a project was successful or not was very subjective and there are no general criteria to give a pragmatic evaluation of this type. It is also debateable that publishing a report of an unsuccessful project is not a common practice either (Cook & Therrien, 2017; Dawson & Dawson, 2018). A couple of criteria were used to determine if a project could not be considered a success:

- A considerable part of the objectives or hypothesis for the project were not met or proven wrong.
- The discussion, results, conclusions, or any similar section heavily focused on problems and negative outcomes without mentioning significant positive or successful ones.
- It was not possible to build or test the intended project, or the design had to be significantly altered, especially for technical reasons.

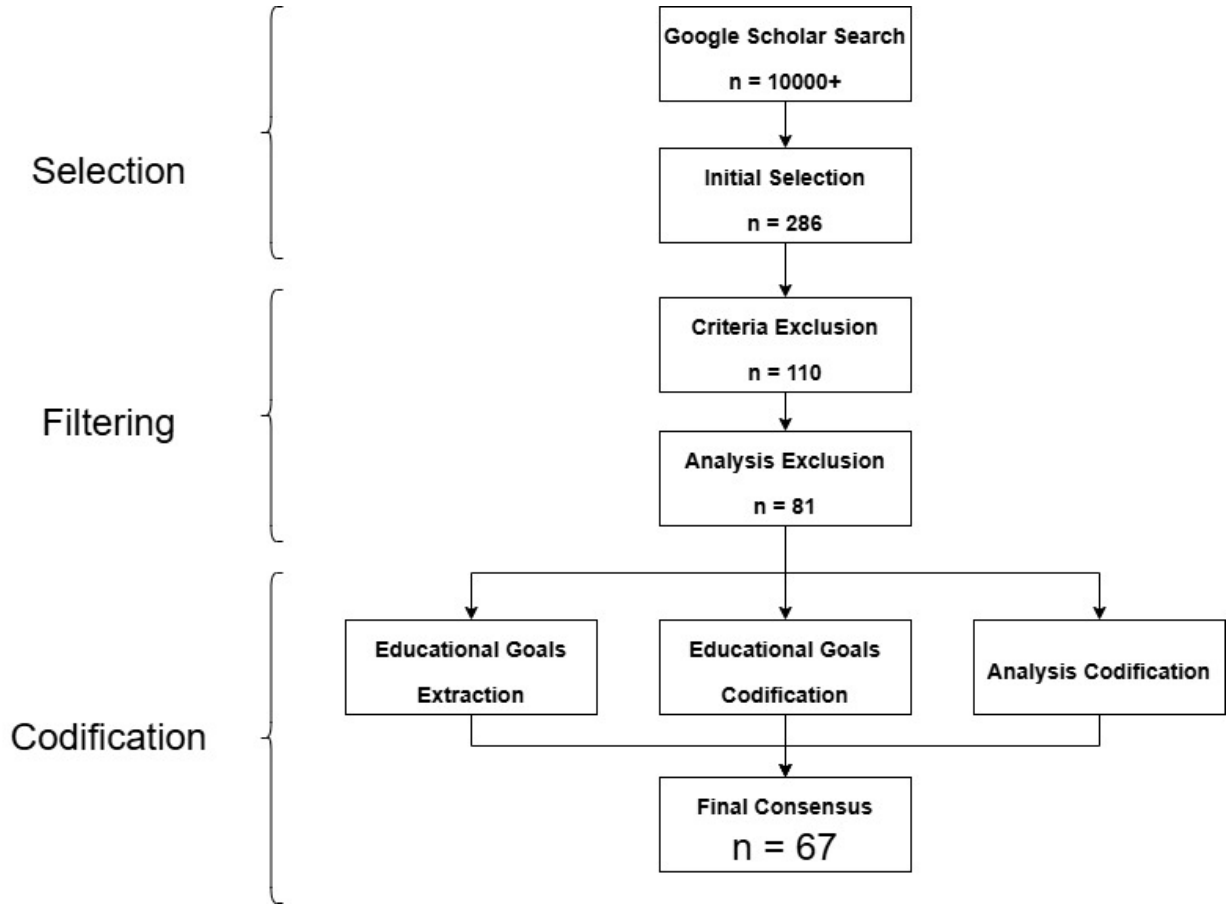


Figure 2.4: SLR Process

The last stage of codification consisted in positioning each pedagogical goal into the BRT given its perceived cognitive and knowledge complexity. For all stages of the pedagogical codification, each researcher gave its own analysis and classification for every text individually by reading the content of each material and following the criteria identified previously. Each researcher gave their own classification regarding: the inclusion of the material in the review, the nature of the intervention, the pedagogical goals, the success of the project and its classification in the BRT. The final codification was achieved by comparing the process between the two researchers, discussing each discrepancy and finally reaching consensus. The final codification for every text surveyed can be consulted in Appendix A.

Figure 2.4 shows the general flow of the process, and the number of documents filtered in each phase until the final count used for the analysis. The process follows the standard recommendations given by the PRISMA statement (Page et al., 2021).

2.2.3 Analysis Phase

In the final analysis, content and thematical analysis was used to extract useful insights of the behaviour and tendencies of the surveyed data, as well as some statistical descriptions used to find categorical distributions, modes and tendencies. Data was organised to identify

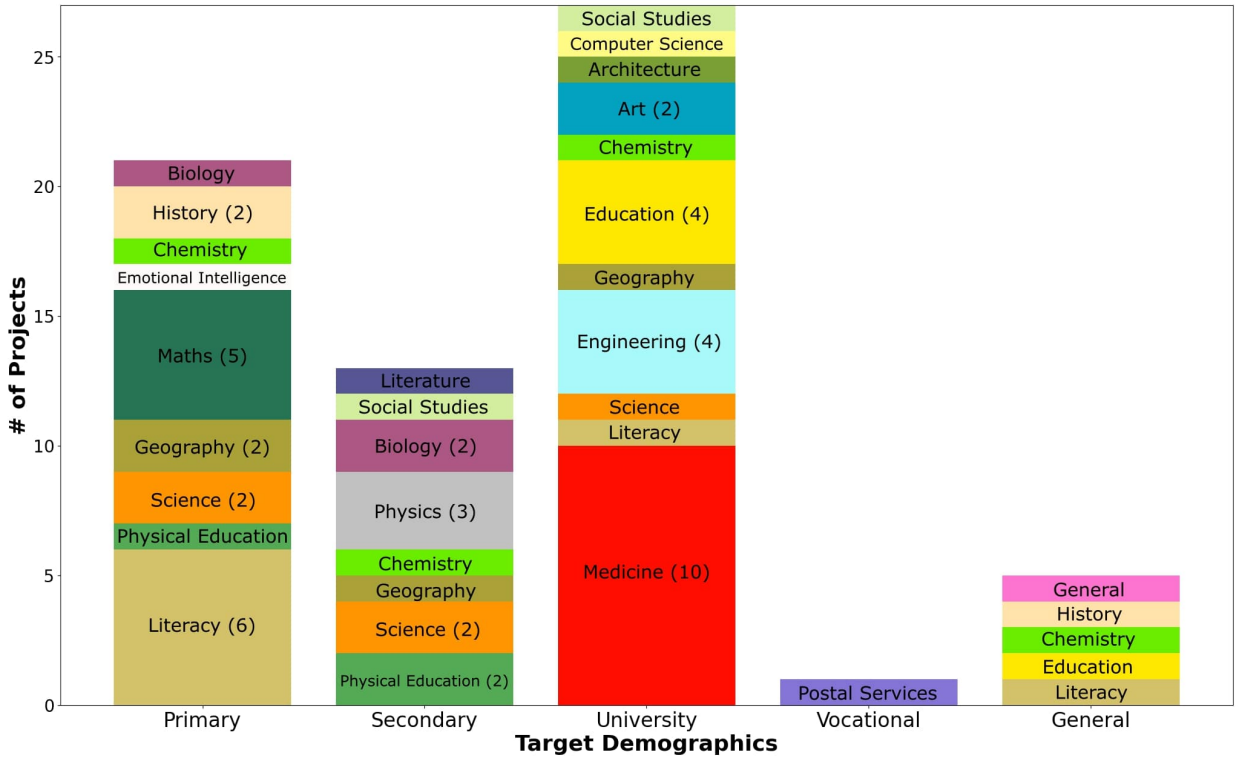


Figure 2.5: Target Demographics vs Target Field

the general distribution of the surveyed projects among different demographics, educational levels and educational fields. More qualitative data was also organized and categorized such as the experiences reported by the researchers and the users, common trends and positive and negative outcomes. Finally, there was an important focus on identify the pedagogical goals targeted by each project, their distribution and significant trends.

Demographics, educational levels and target fields

Figure 2.5 shows the distribution of projects between the target educational level of the students and the field in which the project is providing the educational material. Demographics were divided into *primary school*, *secondary school*, *university*, and *vocational training*. Target fields where coded as general as possible to avoid too much granularity in the data.

University-level education comprises most of the surveyed population and has the most variety of target subjects. Yet, K12 education in general surpasses higher education if the division between *primary* and *secondary* school is ignored. The division was kept because, as the figure shows, there is little overlap of learning fields between target demographics. This suggests that the focus fields for each educational level are well identified and most worked on. Math, science, and language are the predominant focus for K12 projects, with more complex applications of mathematics, like physics, or new subjects like chemistry being more prevalent in secondary education. University projects either focus on field specialisations (medicine in general, surgery training specifically, for example) or in common learning abilities such as critical thinking or problem solving. Little was found in vocational training using AR.

A fifth category emerged from the data and was labelled as *General*. It refers to projects aimed at creating a tool or experience focused on a particular field but not for a particular demographic, instead meant to be accessible by anyone or to present a broad approach to the field with a loose or no focused learning goal at all. One project was classified with a *General* field and *General* demographics, a metacognitive tool meant to help in the process of studying itself with issues like concentration and motivation.

An effort to create tools for learning languages is notable, used mostly as a tool for heavily ideographic languages, like Mandarin, or as an aiding tool to boost retention or even creative skills. Other projects were related to areas that could not be classified by the BRT, like physical education or emotional intelligence. Those projects were kept in the survey because it was possible to code all other data not related to the classification in the taxonomy and could provide some interesting insights.

Fields inside the STEM spectrum are a major focus for any educational research or development, often seen as a priority for a rounded education, career success or community development (Madden et al., 2020). Fields outside STEM, on the other hand, are often seen as underrepresented in research and development endeavours and not given the same importance or focus as STEM fields. In Figure 2.6, fields in red are part of the STEM classification, 52% of the identified fields. This shows almost a half and half distribution between STEM and non-STEM subjects. In terms of volume of projects per field, STEM fields have a bigger volume, taking almost 60% of all the fields identified. Non-STEM fields are present, but in a lesser quantity. Education, or learning to educate (in any field, including STEM) is the biggest representation of non-STEM fields, followed by tools focused on history, general literacy, and alphabetization.

Positive and Negative outcomes

A list of positive and negative outcomes was coded for each surveyed project based on what was reported in the findings, results, or discussion sections. Outcomes were then coded using a theme codebook to identify recurrent ideas and problems. Figure 2.7 shows the recurrences of all the coded themes for positive outcomes. Figure 2.8 shows the recurrence for negative ones. A summarized label was given for each theme, and it was assigned to a broader category to help readability. A full description of each category can be consulted in Appendix A.

Tendencies identified in other studies can also be seen here for both positive and negative outcomes: Enhanced performance and motivation are the most common results, while technology issues in general are the most common reported problems. Aside of these expected results, more surprising findings were also identified. Providing an autonomous educational experience was a positive outcome for different projects. Control over the pace of the learning process, access to a tailored experience or providing alternative tools for different types of learning were common positive feedback. In contrast, positive results associated with socialisation or collaboration were fewer, showing a high tendency to create individual experiences.

Regarding negative outcomes, the most recurring theme is *None Reported*. There is a general tendency to not publish or report any kind of negative results, either to not undermine the general validity of the research or because it is not considered important information to be reported. Is more common for projects derived from engineering or computer science to

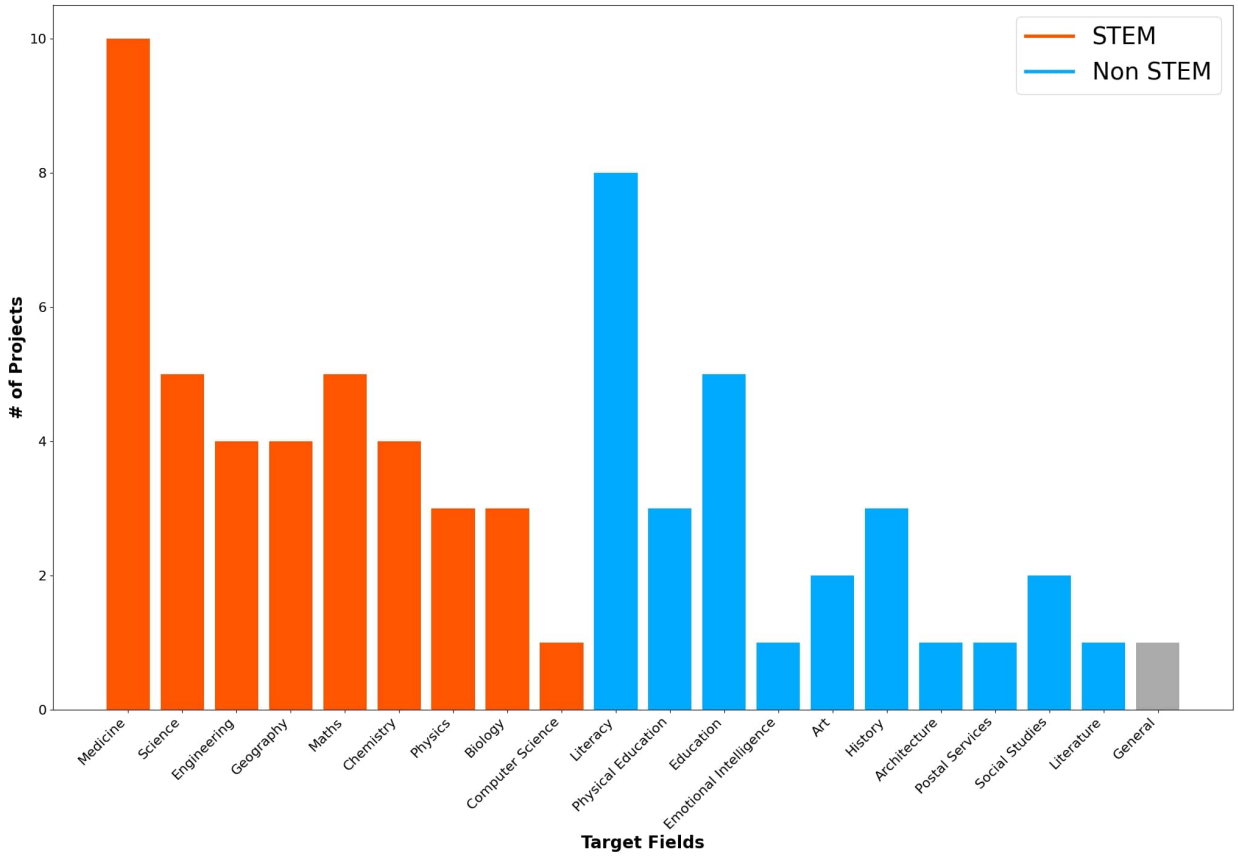


Figure 2.6: STEM vs non-STEM Fields Distribution

be more thorough in describing or commenting on the design and implementation process of the tool, as well as reporting problems or negative results, while projects that are closer aligned to education research or humanities tend to focus more on the results and discussion derived from the experimental design.

Other negative outcomes are related to unintended behaviours caused by using the AR tool. Most popular undesired behaviours reported are constant distractions, hinderance of other skills or excessive time consumption. Another reported outcome is the users perceived lack of quality or quantity of content, or researchers having problems to create content for the tool.

An interesting fact that can be inferred from Figure 2.7 is that most projects guided the validation of their proposed solution by comparing performance gain through the usage of AR. This conclusion is derived from all the positive outcomes related to increased performance, and their absence in Figure 2.8. User validation is another common comparison tool present in discussions and conclusions, commonly in the form of user's perception and acceptance of the tool.

The reported negative outcomes coded were paired with the success classification given to each project by the researchers. Figure 2.9 shows this cross-reference for projects coded as successful, while Figure 2.10 does the same for projects that were coded as unsuccessful.

It can be noted that the density of negatives experiences reported by projects categorised

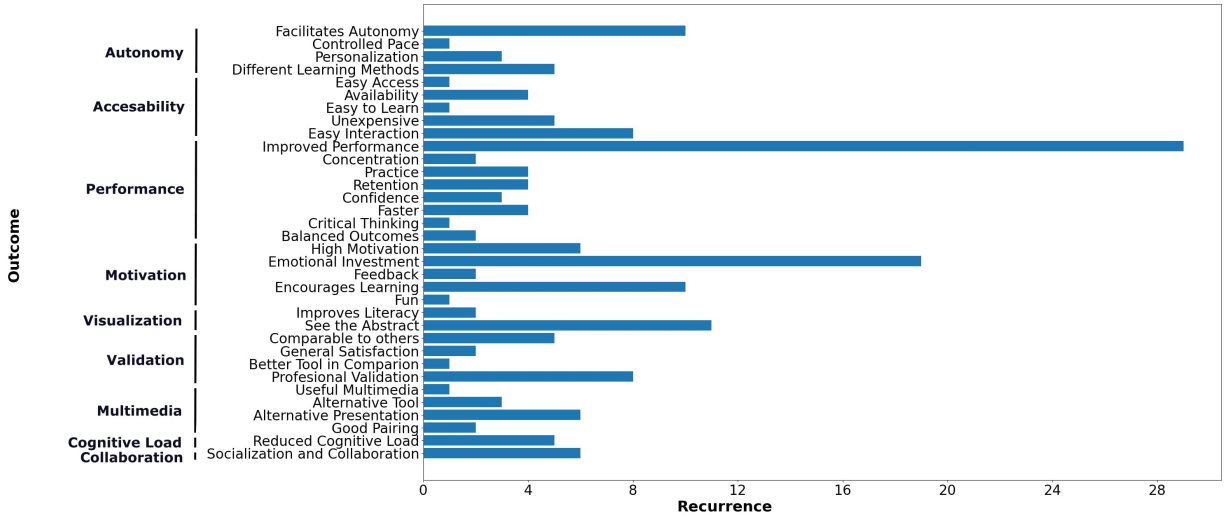


Figure 2.7: Categorisation of Positive Outcomes

as successful is lower than for projects that were not classified as such. Also, projects categorised as successful are more likely to report no negative outcome at all (the *None Reported* category), while projects not categorized as successful where more prone to report technical issues. It could be argued that when technical issues where present, it was harder for users to engage with the tools, resulting in worse perceptions or worse performance results. In contrast, when an immersive, fun, or simply good experience was provided by the tool, technical issues could be glossed over with more ease by users and researchers alike.

Distribution of Learning Goals

Information about the pedagogical goals of each project was extracted and classified using the BRT framework. The cognitive axis is hierarchical by design, and each project was classified with only the highest category analysed for it. For the knowledge axis, several of the possible categories could apply to the same goal and thus were coded like that. Figure 2.11 shows the distribution of points in the BRT matrix for each project. If the project belonged in more than one knowledge category, each pair formed with the corresponding value in the cognitive axis was plotted separately.

The biggest cluster of projects can be seen in the *Understand* and *Apply* cognitive dimensions. *Factual* and *Procedural* knowledge are the most paired with (37% of the total pairings). Most goals tackled by AR educational projects can be found then in the mid to low cognitive complexity, with a preference in applying *Procedural* knowledge. Examples of this can be training in a practice-oriented process, like a surgical procedure, or learning to perform a task, like reading or arithmetical methods. Understanding factual knowledge is the second most common cluster, in which the visualization advantages of AR technologies can help to comprehend concepts difficult to visualise or to get an example of in real life. Concepts in physics or biological processes are common examples.

Several projects were classified in higher cognitive complexity levels like *Analyse* and *Evaluate* throughout all knowledge dimensions, and some efforts were noted to create apps

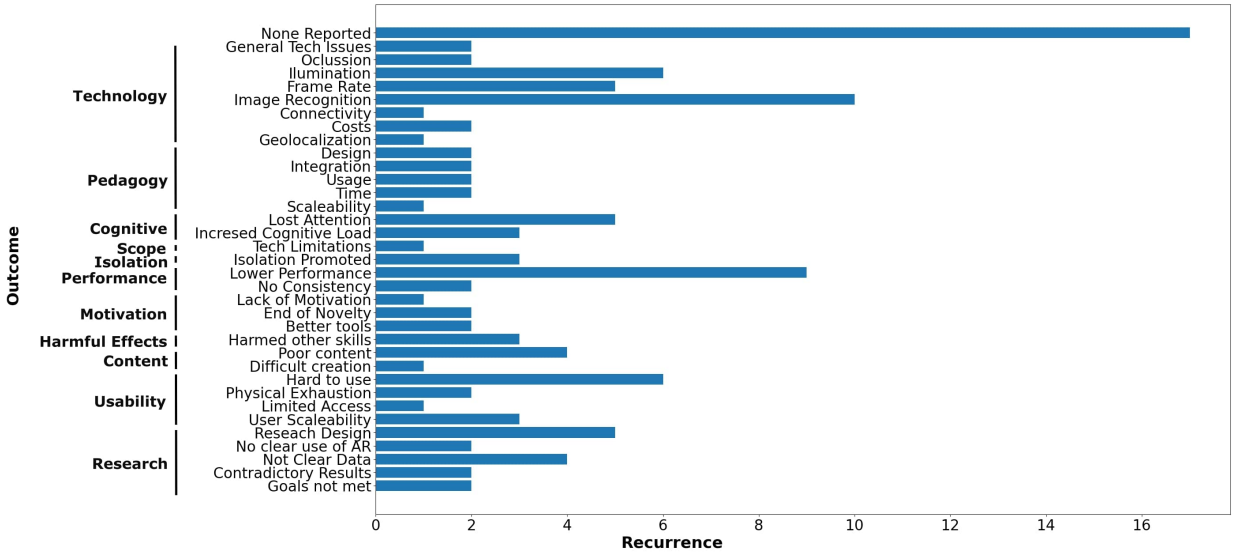


Figure 2.8: Categorisation of Negative Outcomes

focused on creativity tasks. Another interesting cluster is the *Metacognitive* knowledge dimension, with several projects at all cognitive levels trying to use AR more as a complementary tool rather than the main transmission tool of the pedagogical design. This tendency is of notable interest due to metacognitive tools being in line to modern approaches to education like distance learning, long-term learning, learning how to learn and other similar topics. The only gap in the distribution is in the *Metacognitive-Remember* zone, which could be interpreted as mnemonic tools for boosting memory or retention.

Figure 2.11 also cross-references the cognitive-knowledge data with the target demographics of each project. Primary and secondary-level projects coincide with lower cognitive complexity, while university-level projects tend to be in higher complexity levels, though all demographics levels can be found at all cognitive levels in general. University-level projects are more clustered in the *Apply* dimension while K12 levels are more clustered in the *Understand* dimension, which correspond to the common approach each level of education has. The same tendency holds when analysing the knowledge axis: K12 levels are more prone to *Factual*-type knowledge while university level projects are more common in *Procedural* knowledge. The previously identified tendency of projects being in the STEM spectrum can also be seen as a reason for a bigger cluster in the *Apply-Procedural* quadrant in comparison to the lower presence of projects in the *Analysis* or *Evaluation* areas. Figure 12 shows the same distribution of Figure 11 but cross-referenced with a more generalized categorization of the target fields.

STEM related projects are noticeable clustered at the *Apply* section of the distribution. Non-STEM projects are more noticeable clustered in the *Understand-Factual* quadrant and the *Analyse*, *Evaluate* or *Create* regions. In general, the *Remember* region could be considered of little interest or impact for most subjects, hence the lack of points, while higher level cognitive activities get less projects due to the complexity of creating pedagogical designs or tools for those goals. It could be argued that, for those same reasons, no project in the STEM spectrum was found along the *Create* dimension.

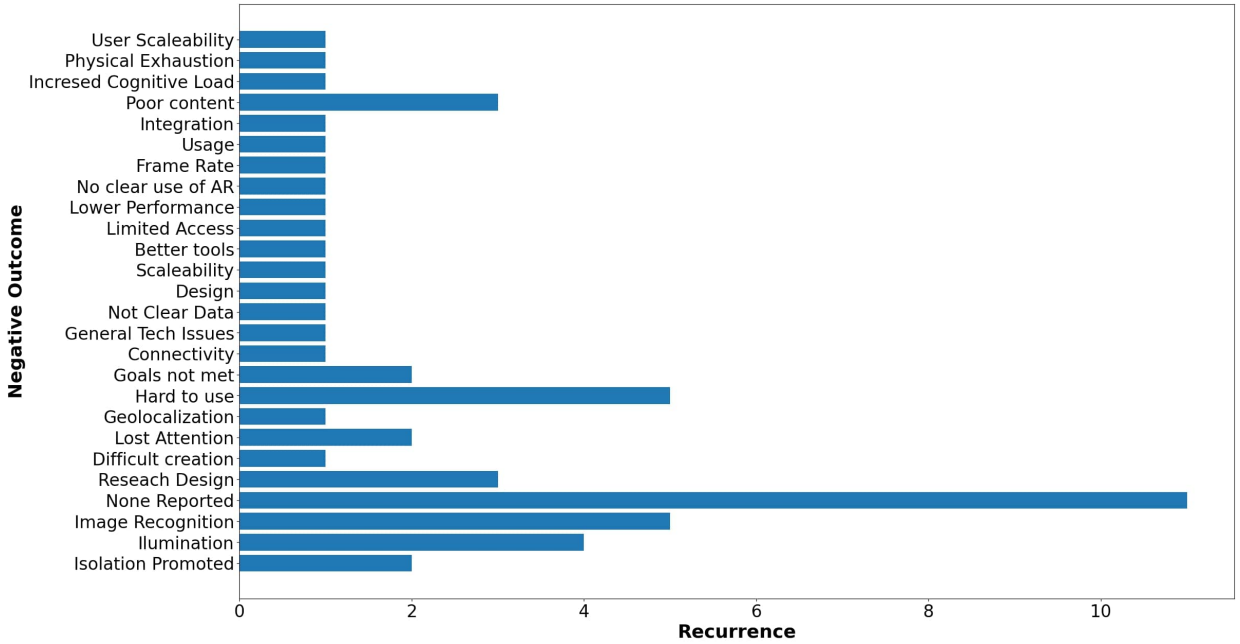


Figure 2.9: Negative Outcomes of Successful Projects

2.2.4 Discussion

The data shows that most projects either focus on *Understand* goals, that is, goals aimed at learning a concept and how to use it, or *Apply* goals, those focused on using obtained knowledge in concrete situations. Primary and secondary level education leaned more towards *Understand* goals while universities and vocational training preferred *Apply*-style ones. When used in a professional context, the prevalent use of AR seems to be as an aiding tool rather than as a learning tool. VR technologies are the main option when training is needed in the workspace, which was outside the scope of this review.

Metacognitive tools were present at all levels, showing an increasing interest in learning-how-to-learn approaches. More complex cognitive goals like *Analyse*, *Evaluate* and *Create* were present in smaller numbers, showing an interest in tackling this kind of endeavour but being deterred by both design and technological difficulties. A small effort to create experiences for the public and with a more product-focus in mind is also noted in a couple of fields.

The visualisation advantages provided by AR technologies are commonly considered as one of its biggest strengths, especially suited for complex concepts, abstract information or elements difficult or impossible to come by. The augmentation element of AR technologies was used often to complement in situ experiences, like museums or laboratories, but it was not as widely used, opting more for a simpler *scan and show* approach. Geolocalisation-based augmentation was used in a couple of cases with a variable degree of success and with several issues associated with the technology. Image recognition approaches are significantly less used and were normally associated with custom-build solutions in need of more development or research.

The primary goal for most projects was to achieve a better academical performance by

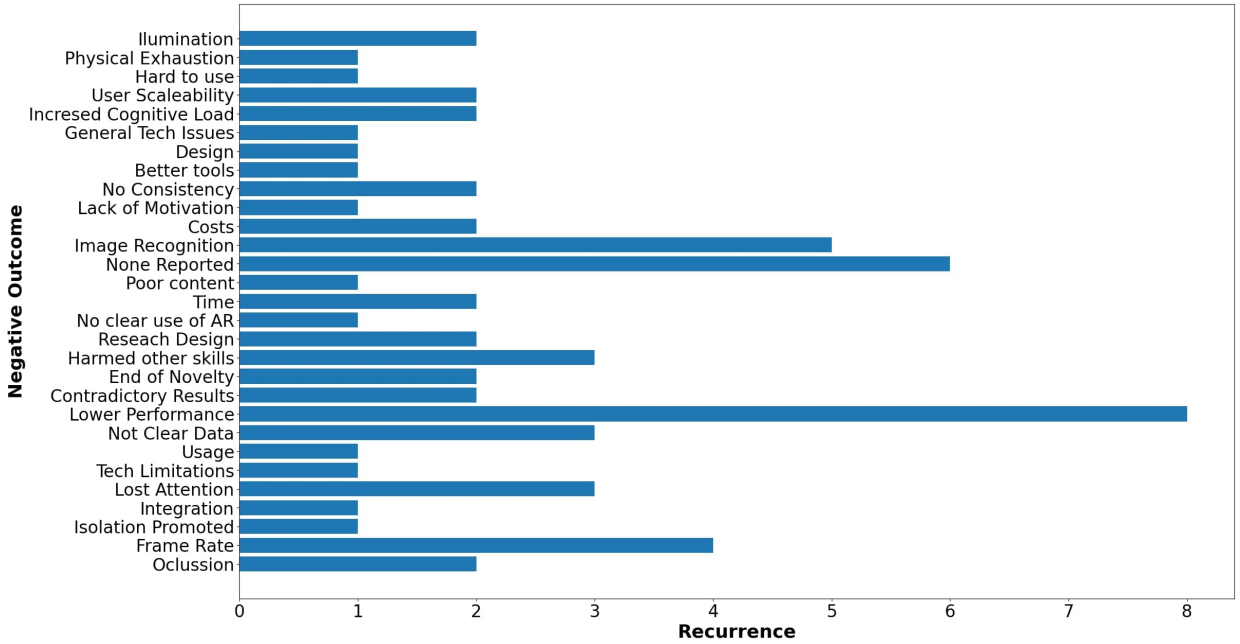


Figure 2.10: Negative Outcomes of Unsuccessful Projects

using AR technologies over other tools or approaches. AR was used to enhance the general motivation and disposition of the students towards learning and to aid the comprehension process through multimedia visualisation, interactivity and assisted practice. Improvements in academical performance were often small but present. AR technologies were commonly seen as more accessible and usable due to the prevalent use of mobile devices as the base platform for deployment and the plug-and-play nature of it.

Although collaboration was a factor in some projects, the general tendency was to create individual tools that helped students to follow an autonomous process. Opportunities for self-paced learning and the ability to have a unique or tailored experience were commonly praised outcomes. This aligns to similar results found in other studies like in Dey et al. (2018) in which the tendency for AR experiences, not only in education, is for individual interactions, with a marginal presence of a collaborative design. It is also clear that AR has been used to explore a diverse number of fields in science, technology and humanities, but is better suited for goals in need of a novel or interactive visualisation or a real-time display of information. Gamification designs that require quick access to information, movement or the visualisation of fictional or no-easy-to-access material are also a good fit for AR technologies. In these scenarios, collaboration is more common but mediated more by the activity rather than by the AR tool.

As for negative outcomes, the most common unintended result is to become a distraction from the educational goals or to impose an extra cognitive load for students, signalling a poor integration between the technological and the pedagogical design. Lack of improvement on academical performance, lack of interest, distractions and lack of content are common reported issues that can be traced to not specifying a clear goal or a clear path to achieve the learning objectives with the use of AR.

Fewer non-STEM subjects were found in the surveyed data, but when present, were often

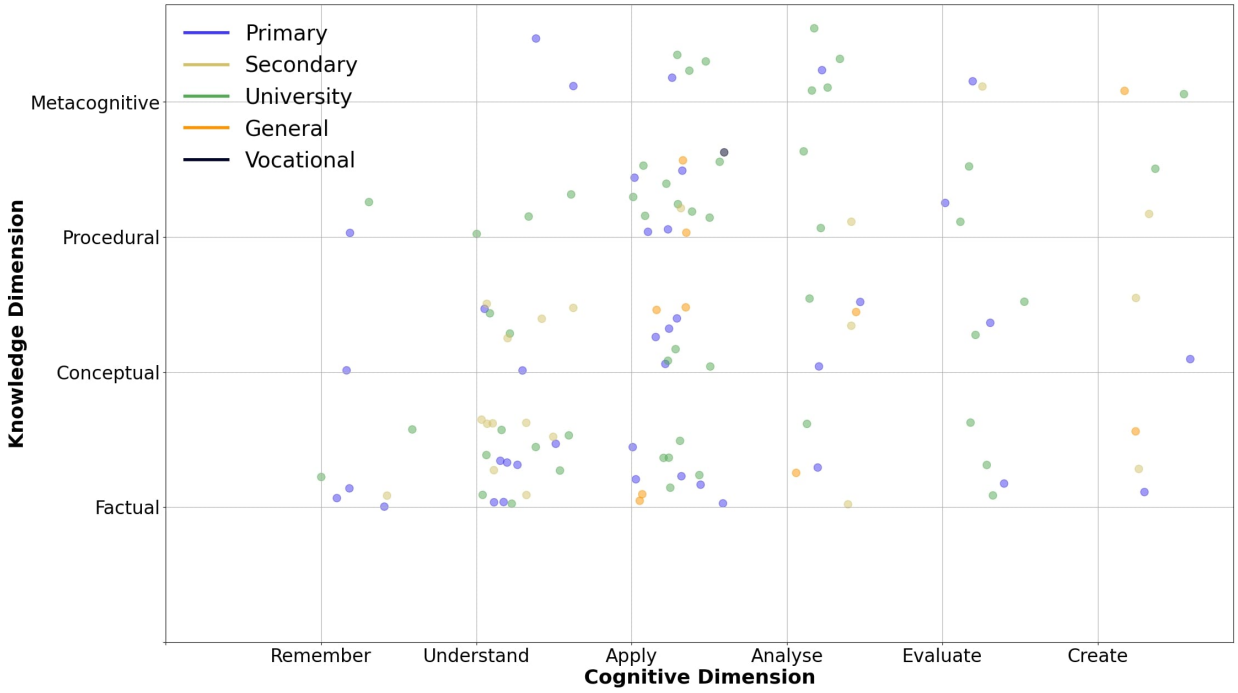


Figure 2.11: Distribution of Educative Goals per Target Demographics

associated with high level cognitive goals. A higher number of projects in subjects like arts or humanities is needed to better understand the advantages and correct uses of AR technologies in these subjects. STEM related subjects, on the other hand, could experiment with more demanding and varied goals, especially in the *Create* dimension.

Validation is mostly done through performance assessment and comparison tests. While offering a good analysis based on data, it also limits the type of discussion to have around the tool, the type of data that can be analysed, and the types of results expected and that can be considered valuable or a success. Understanding not only the statistical gain of the students, but also their experiences, the behaviours observed, positives and negatives, and how the tool relates to the general pedagogical design are also valuable sources of data to consider when analysing the impact and possible benefits of a tool.

Three main ideas can be stated as final conclusions to guide the future development of this research project. First, the identified advantages of AR technologies fit better with *Understanding* or *Applying* abilities, but many examples like Hsu et al. (2019) and I.-J. Lee (2021) show the value of proposing more complex goals or testing the technologies in unconventional ways. There is an opportunity to understand how the technology behaves outside of its most trending usage.

Second, AR technologies are being used mostly as a visualisation tool, with motivation and accessibility as the main driver for the pedagogical design. Improvements in academical performance are achieved using a multimedia approach and appealing to as many different learning styles as possible. The augmentation element associated to AR has not been used as extensively in comparison. This can be explained due to the technical challenges associated with the image recognition process, and how issues in this area affect the overall stability of

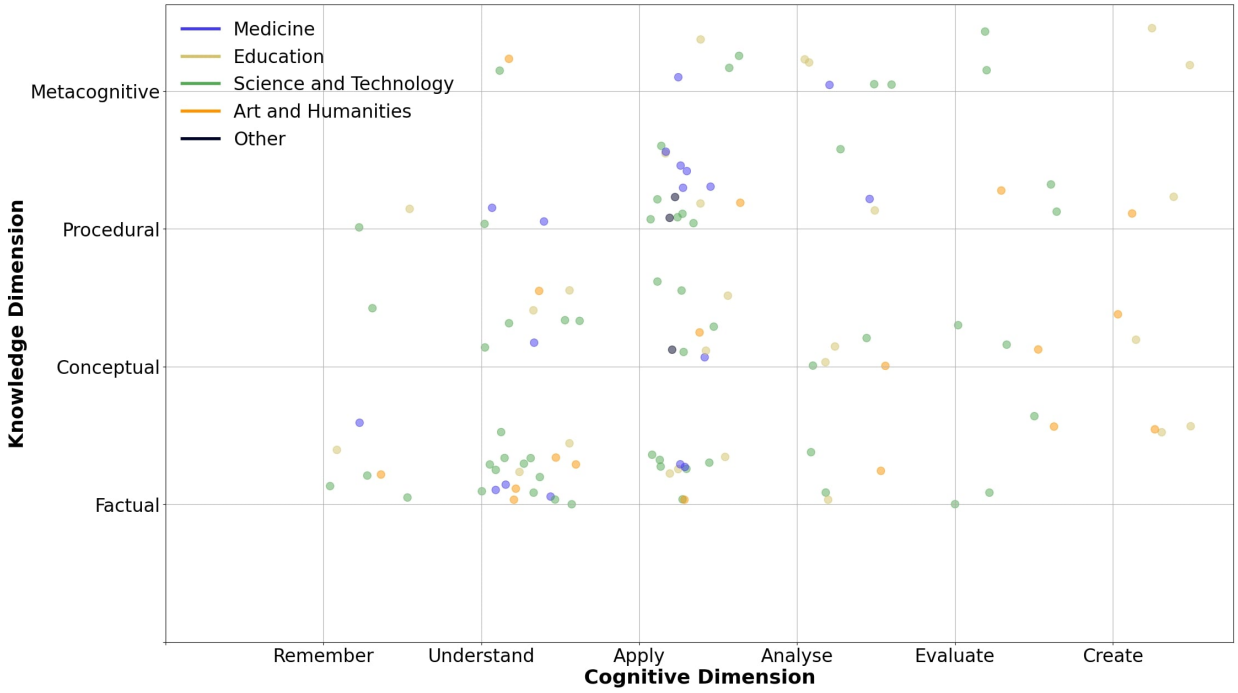


Figure 2.12: Distribution of Educative Goals per Target Subject

the tool and its perceived quality by the users. It is probable that the newest generation of consumer-ready tools will provide an easier way for designers to propose experiences more focused on augmentation rather than only visualisation. Some very interesting results can be achieved when augmentation is the focus of the experience, like in Lim and Lim (2020) or Schaper et al. (2018).

Finally, mobile devices are the most used platforms for development. This facilitates accessibility to the technology and 1-to-1 device usage in any classroom. Yet, most projects found are designed as individual experiences, prioritising student autonomy and promoting a self-pace approach, which under-uses the connectivity advantages provided by mobile platforms. Few examples like Cheng et al. (2019) and Kim et al. (2017) are a multi-user or collaborative design.

2.3 Collaborative AR

From the many insights obtained from the SLR, it is possible to highlight a potential hole in the literature related to collaborative AR experiences in education. A significant majority of the projects surveyed prioritized individual interactions, and those few using multi-user approaches perfectly highlighted the interesting possibilities that the technologies offer around collaboration, teamwork and project-based approaches to learning.

We can expand the information obtained through the SLR and focus some more on the concept of collaborative AR in general, the research done around the topic and the most notable developments found in the literature. If we analyse the topic outside the field of education and consider how AR is being used as an aide in different tasks, we can find multiple

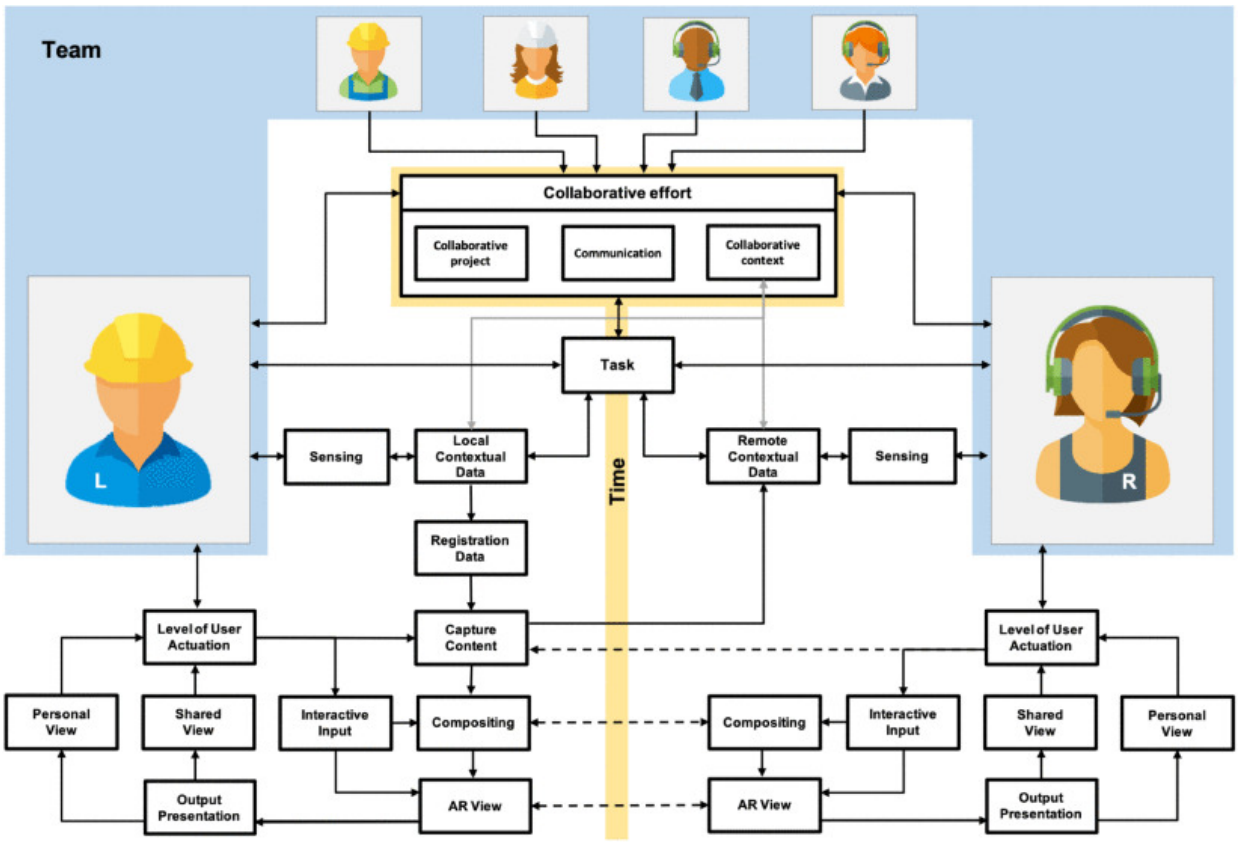


Figure 2.13: Conceptual Model for Collaborative AR as proposed by Marques et al. (2022)

tools that have been tested in diverse scenarios and have been proven to offer benefits and advantages in terms of performance, communication and workload management.

A first approach, before getting into the realm of analysing specific tools, is to understand the domain itself, identify the most important concepts in the core of a collaborative tool and their relationship with AR. Marques et al. (2022) approached the domain of collaborative AR with that same perspective and offered a detailed mapping that can help in categorising and describing any project that could fit in this field.

Figure 2.13 shows the most important components in a collaborative AR tool that interacts with the user and within each other to provide a multi-user environment. Of the key components identified, three main categories can be identified:

- *Context awareness:* Gathering data from the context, either the real space or the actions of other participants.
- *User interaction:* Sensing the actions of each user, each point of view and each flow of information.
- *Composition:* Using data from the previous categories to create the AR view of each user.

These components do not differ much from a generic conceptual model of any AR or MR interaction. The main distinction lies in coordinating all of them through time and different

users. The biggest addition is the category *Collaborative Effort*, composed by the components project, shared context, communication and coordinated effort. These components resonate with the fundamental characteristics off an effective collaboration exposed in section 2.1.4. It also serves as the connective gear between users and holds the bulk of interactivity with the app.

It can also be appreciated that the model does not forces a particular architectural design, save for the general communication pathways proposed between components. Another noticeable decision is to coordinate all the users through the *Task* component, giving the collaborative effort a project-oriented nature and a more hands-on approach to the type of applications that could be designed using this model, which can be seen as a first stepstone for a more detailed proposal in the future. It is also useful as a shared language to understand, communicate and analyse the decisions and particularities of a specific implementation, such as this research project.

In terms of extracting interesting implementation cases from specific applied fields, *Collaborative Design* is a domain in which AR has been integrated into work processes a lot. Different projects experiment with tasks requiring communication of ideas, co-creation of products and balancing the workload of the team members. X. Wang and Dunston (2011) for example, proposed a comparative study that showed performance improvements when using a design pipeline that integrated a MR component. They focused on offering both a face-to-face collaboration process as well as a tangible interaction design using image markers.

Fata Morgana (Klinker et al., 2002) is a similar proposal in terms of implementation, but focuses more on the presentation of info rather than in the interactions with models. The collaboration aspect lies more outside of the tool; its main purpose is to show information while being aware of the context and giving the user freedom of mobility. The Magic Meeting (Regenbrecht et al., 2002) offers a similar concept by providing a physical setup to interact with the markers and the digital models. Again, the emphasis is more on the communication process, where the tool offers the means of interaction with the digital construct, but the main objective is what is happening between the users.

Another prominent field for the use of AR is medicine. The technology has been tested several times in diverse areas like procedure aide, data visualisation and training. When exploring collaborative instances of AR tools, we can find some modern projects focused on helping in decision-making process based on data and consensus, such as the examples shown in Friedl-Knirsch et al. (2024) and Yasojima et al. (2012). But the most prominent application is the use of the technology in procedures using telepresence, tele-assistance or tele-mentoring. AR has been used as an enhanced remote collaboration method, allowing for communication enriched with visual data and real-time interactions. Wisotzky et al. (2019) is one of the most radical examples in exploring the boundaries of the technology. The authors propose a framework for full digital reconstruction of a surgical procedure to enable remote collaboration through AR, highlighting the challenges related to image recognition and network stability. Other projects aim at helping visualise and guide complex procedures and research goals that relate more to feasibility and safety (Alismail et al., 2019; Jun et al., 2023). Other common examples, like Augello et al. (2023), Pooryousef et al. (2024), and Yu et al. (2023) focus more on the display of information, remote or collocated, using a more common marker or feature recognition approach, and providing aid in brief processes, evaluation or mentoring.

Mentoring or aiding students, specially aiding in practice scenarios for surgical procedures, is a major research venue in medicine, evidenced by most of the literature found supporting these types of projects. Just to name a few outstanding examples: Gasques et al. (2021), C. Y. Huang et al. (2018), Moro et al. (2021), and Schott et al. (2024) all show interest in providing students with tools to understand and practice learning material through visualisation and interaction, while also using a collaborative learning approach.

Other fields also focus more on using AR for communicating ideas rather than direct interaction with the immediate context. The augmentation is focused on giving form to abstract concepts or superposing non-existent elements into existent ones. The collaboration aspects focus on sharing the visualisation or interactions between users, or giving presence to remote users in the collaborative task. Some examples of note can be the project proposed by Garbett et al. (2021) in the field of construction, Shen et al. (2010) in collaborative product design, Ahn et al. (2019) in architectural design and Sanabria and Arámburo-Lizárraga (2017) in arts and creative processes.

Telepresence and remote collaboration appear to be a common goal, but it is also possible to find examples that prioritise face-to-face collaboration in diverse activities. The Collaborative Web (Billinghurst & Kato, 1999) explores the concept of collaborative browsing, sharing information and points of view. The work of Billinghurst and associates in general provides a fundamental view of the challenges and possibilities related to collaborative work in AR and focuses on identifying key design issues around interaction and the technological framework that can be used to propose a solution. Another fundamental example is The Studierstube (Schmalstieg et al., 2002), which shows the necessity of an interaction design process of tools like this. Operations in a 3D space that are shared with other people are too distant from more common desktop or mobile interactions, thus requiring extra work to properly build an interaction proposal.

Modern and early incursions with the technology offer a valuable list of considerations for common scenarios like shared interactions, communication between users and co-located activities. From the reviewed material it can be established that several issues need to be addressed in the design stages of any AR solution of this nature:

- A library of interactions with the physical and digital environment that is intuitive, usable, easy to learn and that accommodates the hardware being used. These interactions must consider the 3D nature of the technology.

- A protocol for communication and interaction between users. Co-located experiences should capitalise on the ability of the users to be close together, but solutions must consider issues related to coordination, change in points of view, distribution of tasks and general connectivity issues.

- A clear integration with the overall purpose of the tool. This is important when the tool is meant to be a complement to bigger processes, like and assembly line, maintenance or training. The tool should considerer the time and effort required for set up, tracking, interaction, changes of focus and priorities, establishing communications, among others issues. Good examples of projects dealing with these types of issues can be found in W. Huang et al. (2013) and Tang et al. (2003).

This small sample of projects show an interest in providing the users tools to discuss and communicate ideas, using the capabilities of AR to give a visual anchor to the concepts being exposed and to interact with them. An emphasis on offering tangible interfaces shows the importance of providing a sense of *physicality* to the digital information used in the task. It also provides an interesting analysis of different approaches to interaction design. AR solutions often need to deal with issues related to interactivity and interface problems that are unique to projects delving in 3D spaces or that want to use the user's natural body movements as a mean for interaction.

One final step in the analysis of the available literature is to situate collaborative AR in the field of education. The SLR in section 2.2 analysed analysed AR in general as a tool for education and found an important focus on single user experiences. Those projects providing collaborative designs were few and showed us a research field that offered interesting possibilities and was currently underexplored. Upadhyay et al. (2024) is a more recent SLR that not only explores AR technologies in education but also focuses on experiences using collaborative design and collaborative learning.

The review identified the importance of mobile technology for AR development and collaboration practices, being the most common deployment environment and the most common technique used for implementing collaboration. Even more notable in comparison to the results found in the SLR of this research is the educational approach used by several of the reports reviewed. Projects like Radu and Schneider (2023), Schiffeler et al. (2019), Vassigh et al. (2020), and Xefteris et al. (2019) not only explore diverse learning objectives, but they also explore AR technologies beyond engagement or performance gains, evaluating aspects like communication behaviours, social interactions, induced behaviours (positive and negative), attitudes towards the learning materials and changes in learning processes.

Overall, reported benefits align to concepts already discussed in previous sections and fortified the position of this research to focus on visualisation, interactivity and mobile communications. When analysing challenges identified in the reviewed material, different authors highlight a couple of interesting ideas. Primarily, there seems to be strong trade-off between offering a recognisable environment through mobile technologies that users can easily interact with and the difficulties the students and teachers found in managing new systems and new process. It is important to consider that any technological intervention in the classroom implies a high degree of effort in integrating it to the normal flow of the learning experience. It requires effort for the technology to become and enabling factor and not an inhibitor or a distraction.

There is also an interesting side effect when assessing the impact of the technology in learning outcomes. Section 2.1.4 briefly mentioned that collaboration is difficult to assess. This difficulty can be exacerbated when paired to other, sometimes contradictory learning outcomes, and when the assessment does not consider the raw effects of collaboration in the results, positive and negative. The same can be said about the noise in the students' performance created by the addition of an intervening or mediating technology. In conjunction, a collaborative approach that uses a mediating technology (not only AR) poses a significant challenge for evaluation, performance assessment and other similar tasks. This can be evidenced by the diverse and sometimes contradicting reports found in the review by Upadhyay et al. (2024) and the one performed for this project in relation to what works and what not.

2.4 Final Discussion

This chapter explored the theoretical framework that supports this research project and examined a varied selection of relevant literature related to the most important issues and research trends in the field of collaborative learning, TEL and AR.

This analysis helped in defining and understanding collaboration as a skill that must be built over time with proper nurture and resources. Collaborative approaches to learning can both aim at developing the necessary skills for effective collaboration and at using those skills, such as teamwork, communication and resource management, to boost individual performance, create opportunities for emergent learning and offer educators tools for better classroom management.

It is especially relevant in the exploration of different TEL scenarios to understand the diversity of configurations and tools that can be used and the short-, medium- and long-term consequences for learning, skill development and teaching. Any technology offers benefits and detriments to all these dimensions, and as researchers and educators, it is part of our responsibilities to understand them and manage them.

AR, as any other technology, has proven to offer unique advantages for education, capable of creating strong visuals, immersion and interactivity. It excels at integrating with the user's context, at providing means for exploration, at data-driven scenarios and, central for this proposal, at facilitating shared experiences. On the core of this research project is the idea that, in conjunction with mobile platforms, AR provides important advantages to the design of collaborative learning experiences by using the physical context of face-to-face collaboration and by innovating and recontextualizing the design of tools for communication.

But it is also necessary to highlight the challenges and issues posed by the chosen technology. It is especially interesting to explore solutions for problems related to connectivity, the diverse ecosystem of AR devices, the negative effects in the development of social skills and the challenges students face when adapting complex process and requirements into their learning projects. It is clear that the technology can be both an enabler and an inhibitor. The goal is to identify the proper approaches to boost the advantages while minimising or mitigating the problems.

In the next chapter, the objective will be to use the information gathered in this chapter to properly structure the research and development goals that will guide this project. The current state of the art helped at defining a useful conceptual model about collaboration, the development of collaborative skills, collaborative learning and collaborative AR development. With this information at hand, now it is possible to explain the formal methodological approach for this research and define the proper instruments that will help in the constructions of and answer to the questions formulated by the motivational background of the research and the gaps in knowledge found in the literature.

Chapter 3

Methodology

The following chapter will detail the methodological decisions taken for the development of this research, as well as an outline of the theoretical framework that supports the procedures followed and the limits identified in the methodology proposed.

The first section will focus on the research strategy, the philosophical background used to support the decisions taken, the approach selected for the research design, and the limits and constraints imposed by those decisions. The second section will explain the theoretical framework that supports both the educational research and the software development aspects of this project.

The educational foundation used is based on the views proposed by social constructionism on how knowledge is built and the effects of social interactions and cultural context in the educative process. This project is also strongly linked to a collaborative learning approach that uses those fundamental ideas in social constructionism for the proposed learning design, assessment and analysis processes at the core of this project.

Finally, the technical approach will detail the process used for the design, development and evaluation of *WorkshopAR*, emphasising the design philosophy followed to involve as much as possible the input of the user. This approach was used to better integrate the learning design (of this project and of the target course) into the development of the software. This can be evidenced in the design exercises proposed during the construction of the software.

3.1 Research Strategy

This project is qualitative and exploratory in nature. Qualitative because at the core of the research questions, there is the idea of description. The goal is to describe behaviours and characterise the technology selected as it is used in the classroom. It is exploratory because, rather than trying to corroborate or to formulate a theory, the goal is to gather enough data to understand the characteristics of the scenario being studied. This will allow a deeper analysis of the issues and questions that stood out through the review of relevant literature and previous experiences in the field.

Critical Realism (CR) wwas identified as a good fit for the philosophical approach of the research. Observation will be at the core of the enquiry process and the data gathered will be subjective in nature, linked to very specific points of view: the observations of the researcher

and the perceptions of students and teaching staff. CR proposes an approach to research that takes into consideration the imperfections inherent to understanding reality through such subjective perceptions, finding value in identifying and gathering different views of the same issue (Bryman, 2003; Hastings, 2021).

Since the main source of analysis is on very specific points of view, it is important to understand and accept that any data and observation will be flawed and that all results proposed, especially those that try to identify the underlaying mechanisms in the social phenomena observed, will be in need of interpretation and contextualisation to assess validity or applicability beyond the case study here exposed (Easton, 2010).

Section 2.2.4 explored the tendency found in literature to give the research validity using a very positivistic framework of analysis. This is done by justifying any educational development through improvements in average grades or similar gains, while neglecting or obscuring the human and social core of education. CR ffers a midpoint between positivism and social constructionism by acknowledging the social dynamics used in learning processes, but also grounding any analysis with a more empirical understanding of the mechanisms working underneath what is observed (Parra et al., 2021).

Both Carter and New (2004) and Scott (2005) highlight that one of the most important tools in CR research is to identify agency and structure, to understand the phenomenon being observed by identifying who is doing things, what are the social connections at play and the reasons behind the actions being observed. This approach requires the presence of both empirical, hard data that can be analysed, as well as a more interpretative and qualitative approach to those elements in the data that cannot be described with just numbers.

CR is also a framework well suited to answer *how* and *what* questions. Saxena (2021) explains that the Empirical-Actual-Real model used in CR (see Figure 1) can be used to explain ideas about causation, correlation and the underlying structures driving the empirical events we are experiencing. The research questions proposed for this research both align to this view or were tuned to align with this approach. The main objective is to describe what is happening in the classroom around the mechanisms of collaboration and the technological tools created as an engine of those mechanisms (the what, the empirical), and to create an analytical and interpretative framework to explain those behaviours (the how, the actual). The research process will potentially identify a link between what was observed with the ideas, designs and tools created.

Given the emphasis on observational qualitative data, the best research type that fits the methodology so far described is an inductive approach. The main question (MQ) of this research is aimed at understanding how Augmented Reality (AR) promotes observed behaviours, while questions SQ1 to SQ6 help describing the data with the goal of linking the empirical data with the actual mechanisms in play throughout the educational scenario. The assumption here is that those mechanisms in fact exist, and that they are being built or promoted by the technology developed for the educational design proposed.

It is important to clarify that the explorative nature of the data will not be totally blind. It will be informed by a series of expectations and hypothesis about how AR has been used in the past for educative scenarios and the theoretical background found in the literature about collaborative learning, project-based educational design and Technology Enhanced Learning (TEL) experiences, all which were explored in Chapter 2. This background provides the biggest foundational ideas that will guide the analysis process of the data:

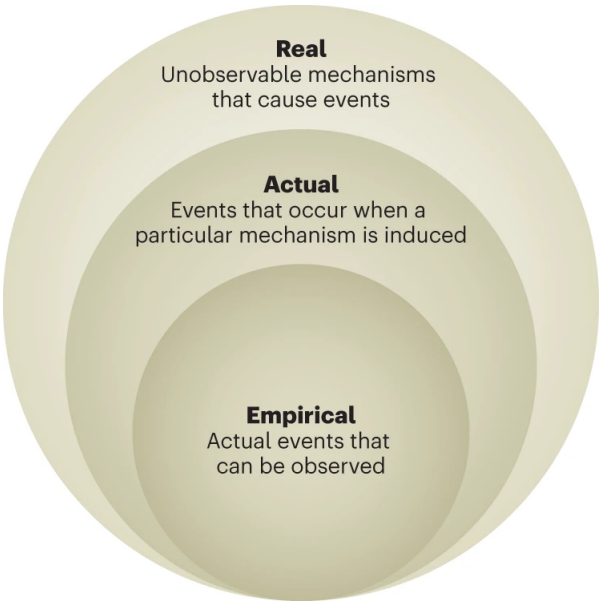


Figure 3.1: The Relationship Between the Real, the Actual and the Empirical (Blackie, 2023)

- AR can be used in education as an effective tool for communication and it works by exploring the advantages inherent to the technology in the form of visualisation, interaction and connection with others.
- The core of collaborative learning lies in using social connections as the main driver of the educational design, and the main behavioural changes that could be observed will be present in those points where AR is part of the social interactions taking place.

The analysis process will naturally try to find indications of those ideas in the data, mainly because it has been apparent in the results found in previous works. It is also important to understand that the main research drive of this project is to identify all those elements that do not align with those ideas (if any), try to link them to underlying mechanisms and refine those initial ideas based on what has been observed, and create a new or distinct starting point for future research.

Following the research strategy chosen, it was decided that a case study would fit best with the philosophy and research types adopted. This strategy offers a promising approach to manage the kind of observations proposed, as the research is more interested in behaviours and personal perceptions. A detailed case study is well suited to create the scenario where these changes can be observed, even if it is difficult to identify and understand all the variables and mechanisms operating behind the observed scenario.

Case studies produce the type of context-related knowledge that is most valuable in learning scenarios. They are also a very useful tool for contexts in which human behaviour needs to be observed and in which a community is an integral part of the context (Hamilton & Corbett-Whittier, 2013). Moreover, thematics and problems characterised as rich or complex are perfect subjects for case studies, which have a good set of tools to capture, organise and

analyse extensive narratives, which value lies more on its density and richness rather than the factual data that can be extracted out of it (Grauer, 2012; Seale, 2007).

Cober et al. (2015) and Tay et al. (2017) represent example projects of educational case studies centred around a TEL intervention. They demonstrate and set a precedent of many of the foundations used in this research around technology in the classroom: a design process that involves the users and a feedback loop that adapts to the circumstances observed. These examples also highlight some unique benefits of a case study approach like involving the community as an active part of the research, enriching the ideas generated by using different points of view and facilitating a two-way avenue of the benefits of the research, often allowing the researcher to actively and directly make an impact on the community well beyond the research scope.

Finally the analysis technique chosen for the project will focus on content and thematic analysis. These approaches offer good flexibility to analyse the data obtained from different points of view that are subjective and anecdotal in nature. They help in synthesising large quantities of textual data, organise them and extract relevant points of interest to start building results and conclusions (Kiger & Varpio, 2020; Neuendorf, 2018). Specifically, the thematical analysis of the research will focus mostly on:

- The use of technology to manage team activities in the classroom.
- The prevalence and importance of technological tools while creating channels of communication.
- The interaction between the different tools used by the students.
- Instances of reflection and analysis of the activities in the classroom thanks to the use of the tool proposed for the intervention.

Although these themes are the focus of the analysis, it will be very important to track and identify any other relevant content that emerges during the observation phase, especially if it is related to the collaboration process or the use of technology in the classroom. Additionally, these same analysis strategies can be used in the evaluation process of the software development, offering a structured method to gather and analyse qualitative data about the usage of the tool and the perceptions of the users using during controlled tests or the intervention in the classroom.

An important effort is also proposed to offer some triangulation to the data obtained from the case study. On one hand, the software development process requires a substantial data analysis coming from the reported results of similar past projects and from the exercise in user-centred design that will be followed during the initial stages of development of the tool. This process is also iterative in nature, and the feedback collected and analysed during the testing stages will inform not only the development of the tool, but also the observation process.

A second approach for triangulation is the use of two extra data instruments to complement the observations. One is focused on unstructured interviews with the students with the objective of gathering data about their collaborative process, their approach to teamwork and the tools they used to work. The second instrument is a similar set of unstructured interviews

focused on the teaching staff. These interviews will gather information about the influence of teamwork and collaboration in the educational design of the course, the criteria used by the staff to assess successful teamwork and their personal views on how these project-oriented activities could be used to prepare the students for their professional lives.

3.2 Research Constraints and Limits

The biggest constraint on the timeline proposed for the development of this research is access to the Industry Project course. The observation window to gather data for the case study is one academic year, which can be translated to 24 academic weeks along two semesters of 12 weeks. This situation forces the project to adapt a cross-sectional approach, detailing as much as possible the technological intervention through one cohort of the course. The main objective is to create an internal comparison between those groups participating in the course as they would normally do versus those using the AR tool. As with most cross-sectional studies, this approach offers a quick way of gathering data and to cover multiple variables of interest that can be analysed later, at the cost of creating a situation in which the data will be biased to the particularities of this sample, making it harder to propose any generalisation or causality (X. Wang & Cheng, 2020).

Sampling inside the cohort of the course will be guided by convenience and the disposition of the students to participate in the research, since it is important to prioritise their academical work and minimise any disruptions to the classroom. Observations will be organised in singular work sessions that the students will be asked to participate in. Each work session will be guided by the students, setting the goals of the session based on any requirements they have during that instance of development of their project. The observation will try to focus on different aspects of the course that had not be observed previously. The researcher will also try to show the students a different aspect of the AR tool, one functionality at a time, facilitating their involvement in the observation and helping with the iterative development of the software. If possible, the observation will try to gather different work sessions focused on:

- The initial contact and formation of the group.
- Understanding the project and gathering information about it.
- The initial design proposal and the flow of information between the different roles in the group.
- The creation of material for the project.
- Evaluation and correction of the material created based on the feedback of the teaching staff and their peers.
- A final evaluation of the work done by the group at the end of the project.

The observations themselves will gather data of the student's work using mainly audio and video recordings, as well as the personal notes of the researcher. Data will be initially organised based on the week it was taken (to determine the overall development stage of the

course's project), the composition of the group observed and the functionality of the AR tool that was prioritised.

This methodological approach using a cross-sectional analysis of one single case study has clear limits and constraints on the type of data that can be gathered and the overall analysis and conclusions that can be extracted.

First, case studies in general are not well suited for generalisation and extrapolation. The results obtained through this project will be linked mainly to the case study selected and its unique characteristics and may not be relevant to the situations found in other courses with different learning objectives or teaching approaches.

To mitigate this situation, an important effort was made to select a case study that uses all the elements of collaborative learning needed for this research, as well as presenting a unique and interesting scenario that could provide insights usable in future research. The Industry Project course offers an interesting view on how students organise themselves around intensive teamwork activities and showcased a variety of approaches to solve problems and to the use of diverse technological tools that can be appliable to many other situations.

Nonetheless, it is important to acknowledge that the conclusions extracted form the data analysis will be strongly linked to the activities and learning objectives present in the Industry Project course and to the situations emerging in the cohort observed. For a better triangulation of the data obtained and to be able to draw more general conclusions, it would have been ideal to observe more cohorts or to apply the tool in different types of courses and activities.

The second methodological limitation is related to the prototyping nature of the software development, which can generate a lot of noise from the friction between learning to use the tool and working towards the work session's goals. This often is evidenced by observations that highlight comments and opinions of the tool around disruptions and issues with the learning curve, which are interesting in themselves and useful for the continuous improvement of the tool, but that can also distract from issues more related to the educational design.

Finally, the predominance of qualitative data generated from this study needs to be interpreted and contextualised. In the same way, the focus on behaviour and underlying mechanism of social activities makes it impossible to create answers and observations that are not subjective in nature and marked by the biases of the researcher. Great care was taken to separate the observations from the analysis. The interpretation of the researcher will be well documented, but hopefully this research will also offer the opportunity for future work to recontextualise and propose different views to the data obtained and documented here.

Considering these constraints, it is important to interpret this project as an exercise in experimenting with the application of a unique technology in the classroom, with the end goal of identifying good and bad influences that could be linked to the use of the technology proposed. In the end, the analysis of the results documented in this thesis can be used as a starting point to develop similar experiences in the future in different contexts, either trying to emulate the same positive results or working on the negative ones, inciting more discussions and pushing forward the understanding we have about the use of AR technologies in the classroom.

3.3 Theoretical Framework

The following section will discuss the main theoretical frameworks that support the two focal points of this project: The educational design around collaborative learning and the software development process of an AR tool to support collocated collaboration.

3.3.1 Educational Approach

The theoretical framework behind the educational proposal is in Collaborative Learning (CL) used as a teaching tool to promote the communal construction of knowledge in the classroom, to play with the strengths and flaws of both students and educators as well as facilitating the development of transversal skills such as teamwork and communication.

Collaborative Learning Structure

CL is seen as a philosophy of education that prioritises communal exploration over uniformity (Eskiyurt & Özkan, 2024). It assumes that learning is an active process that depends on rich context, diversity and is inherently social (B. Smith & MacGregor, 1993). In a collaborative design students benefit from a joint effort to solve problems, a diversity of skills put together for a common purpose and a transmission, active and passive, of knowledge and skills between members of the group (Buchs & Butera, 2015; Laal & Ghodsi, 2012).

CL also goes beyond grouping students for an work, it is an active educational design that seeks to integrate the learning goals of an activity into the dynamics created in the group. Laal and Ghodsi (2012) remarks the importance of creating positive interdependence, where the success of one individual in the group is linked to the success of all the others. This can only be achieved if the learning design allows for the group activity to create considerable and meaningful interactions, mechanisms for personal responsibility, development of social skills, and spaces for the group to self-evaluate (Johnson & Johnson, 1990). CL can be distinguished from similar concepts like peer learning, tutoring and cooperative learning by the way it frames the relationship between students. It proposes an equal relationship between peers that develops high levels of mutuality, that is, interactions that must be executed in both ways of the relationship (O'Donnell & Hmelo-Silver, 2013).

It is possible to summarise the goals of the TEL intervention with three objectives:

1. Use the visual tools provided by AR to reinforce ideas of interdependence and mutuality by highlighting important structures of the collaborative work such as roles, tasks and communal evaluation of progress.

2. Leverage the communication features of a mobile deployment to provide extra channels for meaningful socialisation.

3. Explore the concept of *augmented collaboration* using visuals and interactions to give students a different way to approach elements of teamwork, team management and resource management.

Paired with the requirements of the course, the learning activities that *WorkshopAR* is meant to support are analytical and creative in nature, aimed at evaluating the collaborative

work of the students at a high cognitive level. If the design purpose of the tool is to provide a technological approach to develop the skills needed for an effective collaboration, the observation stage of the project will evaluate if the students that are engaging with the tool are using it in a way that helped them with these learning objectives, either:

- To better organise or show the analysis done to the project through an understanding of the context of the problem, the use of their previous knowledge to propose a solution and communicating their analysis to their peers or the clients.
- As a tool that helps the creative activities needed for the proposed solution by pooling resources, help the discussion of ideas or approaches, help to organise tasks or keeping track of progress.

Observations of this type of activities, positive or negative, will be used to construct a satisfactory answer for the research questions, and will show that the tool is indeed highlighting the aspects of collaborative work that are meant to be reinforced: organised and meaningful interactions plus a structured way to manage the interdependent activities taking place in the group.

Available literature has also identified major obstacles that have to be acknowledged when proposing a CL design. Section 2.1.4 highlighted the most relevant literature found around this discussion. Other relevant work like the one present by Hansen (2006) and Pfaff and Huddleston (2003) also offer an important analysis of the challenges found in collaborative settings that where critical in the design of *WorkshopAR*. Of the ideas mentioned, it was considered important an interesting to emphasise:

- The imbalances in dynamics, power and assessment that are often found in teamwork and how the students negotiate and work with them.
- The hurdles in communication that often are the focus of friction and failure in a team.

Finally, this is also an exercise in collaboration mediated by technology. There is ample discussion on the phenomena of online collaboration (Hathorn & Ingram, 2002; Rodchua, 2017), but the proposal of *WorkshopAR* is to identify how this trend of asynchronous and discontinued communication is used outside the web and in the physical classroom, with the main intention of identifying, if possible, positive or interesting behaviours that can be nourished to create a more positive relationship with technology inside the classroom, akin to the proposals made by authors like Dyer et al. (2015) or the analysis of available options and approaches from Olson and Olson (2012).

Social Constructionism

If CL is the central pillar of the educational proposal of this project, then social constructionism is at the core of the educational philosophy found in collaborative learning. One of the main premises of social constructionism is that the cognitive development of people matures thanks to the guidance and collaboration with others (Rogoff, 1990). It is impossible to learn in complete isolation.

In this model of learning, communication is a key ingredient since language itself is the main driver for the construction of knowledge and the core medium for its transmission (Renzl, 2007). The immediate context, the cultural background, cultural artifacts, the relationships that had been build and the sense (or lack of) pertinence to a group are all fundamental factors in the process of creating knowledge, and they are all inherently social (Burr & Dick, 2017; Edley, 2001). It is no surprise then that CL echoes all these elements and bases most of its methodological approaches in social constructionism premises:

- Focus on learning and working in small groups to facilitate the creation of meaningful relationships.
- A prevalence of discussions and debates as the main tool for the creation and transmission of knowledge.
- Use of tools that support communication.
- Guidance and mentoring as the primarily teaching intervention.

It is important to clarify that this research takes a stance in social constructionism and not in constructivism. The main reasoning follows the definitions used by Rob and Rob (2018). This research is focused more on the social aspects that can be observed in the case study, it is more interested in the behaviours of the group and the way communal knowledge is built (which aligns better to the approach of constructionism) rather than the cognitive process of the individual interacting in the group (a more constructivists view). In the end both terms are rather interchangeable and complementary, and both views agree in the fundamentals, but it is an important distinction to establish and to keep consistent through the research.

Another important distinction is between weak and strong constructionism. The main difference lies in accepting the existence (or not) of *brute facts*, absolute and fundamental realities (weak constructionism), or rather considering that reality is completely created by social convention and interaction (strong constructionism) (Lawson, 2002; Travers, 2004). In its core, the distinctions are not fundamental for the proposal of this thesis, but a strong constructionist view aligns better with the analytical methods proposed in the methodological design, since all observations are of social behaviours, and need to be filtered and understood through the social context, cultural and linguistic frameworks of the case study. This also supports the view that any observation and analysis done in the case study cannot be objective or completely unbiased. The context around the classroom and the background of the participants and the researcher, among many other factors, are important determinants of the results of this research.

In the case of the Industry Project course, it was considered that the following social factors presented and strong influence on the behaviours observed and the analysis performed by the researcher:

- The course represented the last academical requirement of the program, and all students were close to graduation. This is relevant since all the students already had a lot of experience with academical and collaborative work, and the observation could change substantially if the observed group is younger or in an earlier state of their studies.

- The researcher also fulfilled other minor roles as part of the teaching staff, which could affect the way the students approached the intervention, the responses given and their overall disposition to their work while the researcher observed.
- The students did not have any real obligation to attend the work sessions, and the number of absentees was considerable. The students consistently attending, which in the end represented the observed population, shared common characteristics associated with their compromise to the course and dedication. This situation could skew the observational data to certain attitudes towards teamwork and classwork in general.

Andragogy and Educational Design

The last fundamental guideline is andragogy and the design principles in education for adults and life-long learners (M. S. Knowles et al., 2014). This document has purposely tried to avoid the term pedagogy because it recognises critical elements that characterise an adult learner and that are integral to the educational design proposed for the project:

- **Adult Learners thrive better with self-direction:** The proposal can offer the flexibility needed for the students to explore the material at their own pace and with personal objectives that the learning process could be inciting.
- **Adult learners have a bigger set of past experiences:** There is a bigger pool of knowledge and skills that can be leverage for the educational design.
- **The classroom has a more heterogeneous background:** The classroom benefits and uses the different backgrounds and abilities of the students to boost the collaborative aspect of the learning goals and uses the different roles that the students can support as a backbone for the course project.

The approach to technology proposed by this project also makes more sense, is safer and offers more value in a context with adult learners (Jimoyiannis & Gravani, 2011; Shopova, 2014). Since the proposal focuses on identifying the benefits of communication and collaboration mediated by technology, it is important to balance this approach with the evidence that shows the benefits of limiting access to mobile and smart technologies in young learners (Cheriti, 2025). There are both value and a necessity to create sufficient and actionable digital literacy, but not at the cost of other aspects of development.

Within this framework it is possible to summarise the educational design behind the development of in three main ideas:

- A project based on CL, aimed at using collaboration to reinforce the work done in the course and apply it in a complex context, but also as an exercise in learning the essential tools of collaboration and teamwork to apply them in the professional space.
- An educational philosophy guided by social constructionism and highlighting the importance of transferable knowledge, learning communities and learning spaces.
- A teaching approach based on the necessities and opportunities found in adult learners, benefiting from a deeper and more diverse pool of knowledge and experiences that can be applied in new contexts and transferred to the community.

The following educational design is proposed based on these ideas. To define the learning objectives proposed by *WorkshopAR* it is important to distinguish between the objectives proposed by the Industry Project course and those that *WorkshopAR* is proposing or reinforcing. The development of the case study will be explained in more detail in Chapter 6, but the general idea behind the learning objectives of the course can be explained as an exercise in the analysis, proposal and evaluation of an architectural design for a construction project. Within this context, the teaching intervention proposed for this project is based around the following learning objectives:

> LO1: Plans and follows a structure for a work session that prioritises the accomplishment of a clear goal and identifies the roles followed by all members of the group and the resources needed during the session.
>
> LO2: Collaborates to accomplish a well-defined task that requires the coordination of resources, discussion among members of the group and a process for making decisions.
>
> LO3: Communicates and explains ideas or opinions about a decision to be taken and collaborates with the team to reach a communal decision.
>
> LO4: Evaluates the feedback received by peers or clients to determine what actions must be taken to correct or expand the work done.

These goals prioritise a simple structure in the collaborative process, starting by analysing how the students plan a task, how they organise their work and how they incorporate feedback into their project, closely following the structure proposed for the project itself in the Industry Project course. Additionally, the goals are also separated from the medium and instructional techniques selected for the project. The use of AR, interaction and visualisation is meant to be tested against these goals, which means that observations and comparisons with the other groups not using *WorkshopAR* (and using other types of approaches to their collaborative work) are possible.

The main learning activity associated to the educational proposal of *WorkshopAR* are the work sessions of the students. Within a work session, it is expected that a group focuses on a set of tasks and to use the tool to organise their work and support any discussion or debate. This is an open approach to the activity, meant mostly to facilitate the observation process during the execution of the case study, and to disrupt the work of the students as little as possible. Some structure can be given to the students to guide their work and emphasise better one or more of the learning objectives. Three types of activities can be suggested that are in line with the learning goals and can be useful, especially if the group finds itself a little directionless or without a clear goal in mind for the session:

- Identify long term goals and divide them in smaller achievable tasks. Propose and discuss these tasks, considering priorities, resources, dependencies and the responsibilities of each role.
- Discuss a problem that is impeding progress in the work right now. Propose solutions and discuss how to implement them.

- Identify individual tasks that each role needs to fulfil, either alone or with the help of others. Distribute those tasks and periodically report your progress to the group.

As with the learning objectives, these activities run along the work that must be done with the course without enforcing approaches too specific or that cannot be adapted to the situation of a group. It is worth mentioning that these activities also facilitate observation of how the tool is helping to give structure to those activities by allowing flexibility to use it (or not) in different ways and with different objectives in mind.

The assessment process of this educational design is minimal, and it is concerned mostly on comparing the assessment done for the course between the different observations throughout the case study. Hopefully, it is possible to observe that there is a positive change in results in the groups using *WorkshopAR*, but this research is more concerned in identifying changes and differences during the development process. Nonetheless, some criteria can be established to guide what can be considered a positive or negative impact.

Positive observations can be characterised by constant communication between the team members, coherency between the different aspects of the proposal and a clear visualisation of the decisions taken for the project and the reasoning behind them. In contrast, poor performance can be characterised by a disjointed work without a common or clear objective, noticeable lack of communication between the group and a failure in meeting deadlines or show consistent progress in their work.

3.3.2 Technical Approach

Yadav et al. (2015) establishes that an agile development process with an iterative or cyclical approach is better suited for rapidly changing environments and for the exploration of ideas. The nature of *WorkshopAR* requires a development process that can quickly be adapted and refocused as the testing and observation goes on, when the context of the course is better understood and when feedback from the students is gathered and analysed.

As explained in the introductory section of this chapter, the exploratory nature of the process does not imply that the process must advance completely in the blind, it is guided by several premises that focus the development into achieving the most important aspects of the research goals. First, the development focuses on visual and interaction design, multiuser interaction and communication features. Additionally, despite the initial open nature of the case study, a set of common functionalities can be used to represent the core ideas of CL that can be enhanced through AR. Independent of the particularities of the case study, *WorkshopAR* is conceived and designed to provide solutions for:

- Visualising the interdependence of the group by making the composition of the team clear, the structure implemented and the work being done at a given time. This to offer guidance and promote discussion as suggested by Salas et al. (2015).

- Keeping track of the visual resources used in the work session (ideas, models, discussions, experiments).

- Create a shared experience for visualisation, interaction and communication.

In a similar way, the conceptualisation of the tool was first tackled through a focused design process with the aim of understanding interactions in 3D and how to effectively use the inputs and tools often available in AR technologies. This focused design identified ideas to create an interaction experience that highlighted the advantages of AR for users that in general terms are not familiar with the technology.

User-Centred Design

The first step in the development of *WorkshopAR* is a user-centred design aimed at the interaction aspects of the experience with the hardware and with the AR tools built to accomplish the learning goals established. The main objective is to identify expected interactions with AR technologies and formulate a proposal for the overall experience based on the aggregated feedback gathered from the users.

Chammas et al. (2015) establishes that a user-centred design is characterised, among several other things, by:

- Being project-oriented, tailored to specifics needs and driven by data.
- Interacting and engaging with the user. It is an exercise in communication.
- A constant process of analysis and refinement.

A user-centred design can move in a wide spectrum of implementations depending on how much involvement the user has in the process and the steps in which input has been gathered and implemented. Marti and Bannon (2009) highlight the need of considering the context of the project to determine how much access the user can and should have in the development process, the points in the project life-cycle in which the input of the user is more valuable and the importance of identifying and working with all the different users that a product may target.

The development of this project benefits from a user-centred approach because it is an exploratory context. This type of design process is better suited for scenarios in which the user has a personal or strong connection to the product or when tailoring a solution to a particular population. User input is also more valuable when used to guide research, explore design pathways or identifying issues with an idea or a prototype (Goodman-Deane et al., 2010; Tosi, 2020). Figure 3.2 shows the involvement of the users incorporated through the different stages of the research, but more significantly in the software development process of *WorkshopAR*, using as a basis the stages proposed by Pelegrin (2024).

The biggest risk that needs to be acknowledged when implementing a user-centred design is to mismanage the involvement of the user in the process. As Wilson (2014) exemplifies, this situation can take the form of:

- A lack of expertise guiding the project, which results in only community-driven ideas than can turn out amateurish in nature or not considering the whole extent and context of the project.
- A disorganised input that lacks cohesion and a clear goal.

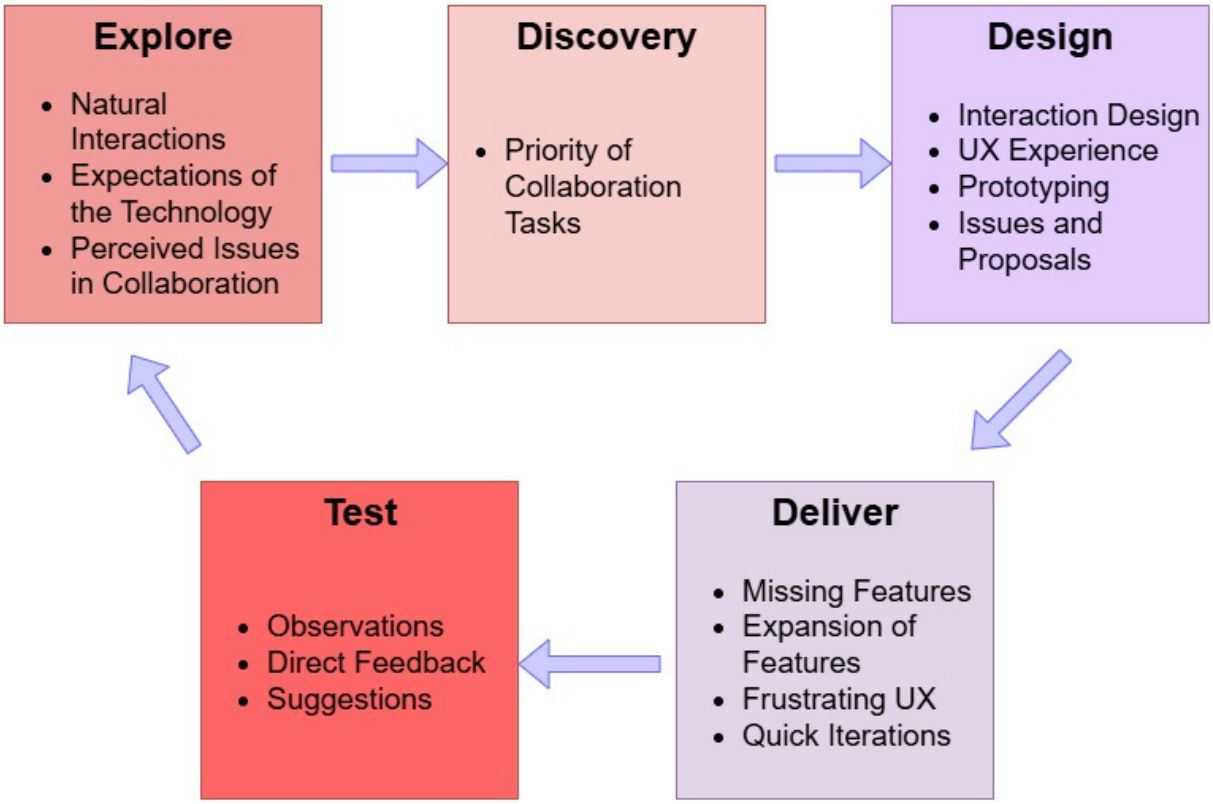


Figure 3.2: User Input in the User-Centred Design Process

- Stumbled progress, usually due to late decision making or relaying on the necessity to please many disjointed voices.

The clear goal of creating a shared space for collaborative work and the learning goals for the general software development and the industry project course help in mitigating these risks. Other guidelines have been established to keep the interaction design focused and to help the analysis and incorporation of feedback in the different stages of the process:

- Mobile-first development. Several aspects of multiplatform interactions will be discussed and tested, but the priority in design will be given to the technology and input methods found primarily in mobile environments, leveraging the handholds and methods present and expected in the medium.

- The main design space will be in 3D interactions and the use of AR to solve problems like the selection of objects, positioning and image identification. Aesthetical decisions and design are important but not the focus of the research.

- AR is a new interaction space for many users, but plenty of sources have shown and tested different designs with positive results. The design guidelines for AR interactions developed by Google DevWorks (ARCore, 2025) are a good example of the available solutions in the current market than can be leveraged and expanded upon without the necessity of reinventing the wheel.

This philosophy behind the user-centred design was also used as part of the iterative process for the software development, especially in support of the analysis and testing steps, as will be described in the next section.

Software Engineering Process

The process proposed for this development is based on the stages and activities recommended by Salo and Abrahamsson (2007) to conduct and agile development process that is constantly checking for improvement and for effective use of resources. The research context in which *WorkshopAR* is developed, and the exploratory nature of the objectives behind the software proposal require for the approach of the development process to be flexible and agile.

The process will be used in the context of a development that tries to deliver functionality fast and in increasing complexity. This behaviour is a response to the necessity of tentatively explore solutions for the educational and technological challenges of the project, to change course, pivot a proposal and be able to incorporate the input of the user participation as explored in the previous section.

As Elbanna and Sarker (2016) explains, agile developments are useful for getting unrestrictive progress in rapidly changing environments, but they run the risk of aimlessly keep producing bloated functionalities and lack a clear direction. For the prototyping nature of *WorkshopAR*, this is an acceptable use scenario, and the same guidelines established to focus the user-centred design process can be used to guide the software development. Additional milestones can also be proposed to evaluate progress and to set a baseline of what can be considered a finished version of *WorkshopAR* within the context of the project.

> Milestone 1: A multiuser experience with shared visuals and coordinated interactions.
>
> Milestone 2: Visualisation of relevant digital constructs for the learning activities and varied interactions with them in a 3D space.
>
> Milestone 3: Tools for communication and team management.

These milestones are general enough that allow movement and flexibility around the objectives to achieve, but they also offer specific criteria to determine if an idea or proposal is outside the development scope.

Time constrains are also an effective tool to avoid an iterative process to spiral indefinitely (Kula et al., 2022; Waldmann, 2011). The nature of the research itself establishes a hard time constraint for the development that needs to consider access to the case study and the work needed for the research outside the software development. Figure 3.3 shows the top-level structure of the development process that contemplates the research and evaluation steps done before and after the development, as well as the need to fit the process with the schedule of the case study.

For the timeframe at hand, it was considered possible to divide the development process into two iterations aimed at two complementary objectives. The first iteration could build upon the previous literature review and early design stages and increasingly offer different

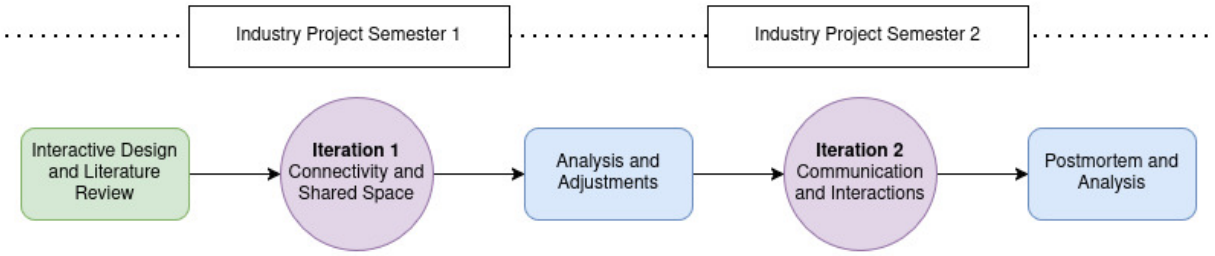


Figure 3.3: Top Structure of the Development Process

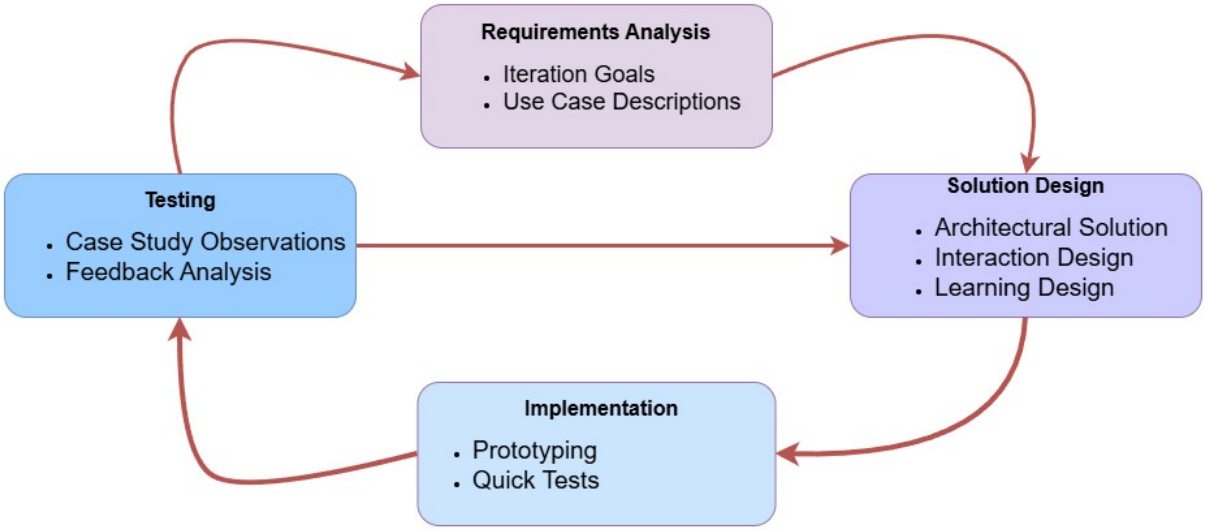


Figure 3.4: Activity Flow of an Iteration

functionalities to the users throughout iteration 2. This model also takes advantage of the flow of the case study that proposes a similar structure and is also iterative in nature.

Each iteration establishes clear requirements and runs through the process several times, gathering user feedback to determine if it can derive in a meaningful change or needs to be tackled in the next iteration. Figure 3.4 shows in more detail these dynamics in a single iteration.

3.4 Conclusions

This chapter has identified and described the major decisions taken for the methodological framework of this research. The strategy proposed is based on a quantitative approach that focuses on exploring the topic of CL using AR through two complementary perspectives:

- An learning design that establishes clear objectives for the development of the TEL intervention. These objectives are meant to develop fundamental skills for effective teamwork and communication and are based in strong educational approaches of social constructionism and good teaching practices for adult learners.

- An exploratory software development aimed at proposing solutions to challenges of interaction design for shared AR experiences. It also needs to propose effective mechanisms to properly integrate itself with the learning design of the target course. This software is developed through an iterative approach that is centred on user feedback, quick adjustments and fast delivery.

The theoretical background explained supports the main objective of this research of integrating a strong learning design in the implementation of a mobile technology intervention in the classroom.

The next step is to describe the results of applying the experiences and ideas gathered through the literature and in the methodological guidelines, first in the design and development that supported the technological approach of the intervention, an then in its use during the interaction with the Industry Project course.

Chapter 4

WorkshopAR - Architectural Design

The following chapter will discuss the architectural design of *WorkshopAR*, the educational software developed to explore the research topic of this thesis and to gather data related to the research questions formulated. This and the following chapters are dedicated to the technical identity of this research and will discuss the development process followed, the technical analysis done to accommodate the educational context of the development, the technical issues found through the design and implementation stages, the results obtained and the path forward for future implementations.

This chapter will focus on the conception and design stages of WorkshopAR, a prototype implementation and proof of concept of an Augmented Reality (AR) technology for education. Specifically, the intention of this chapter is to discuss these main points:

- The architectural design of the software, the challenges that were present in the context of the research questions and the different solutions proposed to tackle them.
- The technology integrated into the proposal and used for the development process.
- The changes in approach and solutions that had to be made in response to the learning design context, the challenges posed by the selected technology and the data gathered during the testing stages.

Additionally, the literature review in Chapter 2 showed four unique characteristics of AR that can be leveraged to help in the implementation of a collaborative learning approach:

- Visualising and interacting with abstract or difficult to come by concepts and objects.
- The ability to keep and incorporate the immediate context as part of the experience.
- A mobile-first deployment philosophy that eases development to an extent and proves to be more accessible to the end user.
- Easy integration with other tools in the mobile environment like cameras, movement sensors, GPS and ubiquitous connectivity.

The literature review also showed that most educational apps are single-user experiences, which undermines the powerful connectivity tools provided by the mobile ecosystem. Multi-user AR experiences (educational or not) excel the most at co-located, in-person activities. The use of GPS-based augmentation also gives strength to this tendency, building connectivity on top of a different framework in the mobile network infrastructure and prioritizing the sense of sharing a common space rather than sharing an abstract connection with other users.

With this information it is possible to establish one of the main motivations for the development of *WorkshopAR*: to create an AR application made for a multi-user interaction that explores the technology's capabilities for digital visualisation, context awareness, seamless connectivity and a strong link to the physical space shared by the users.

The literature review was also used to provide an analysis of the TEL field. It was possible to identify two problems that proved to be the most relevant for this project.

First, there is a clear trade-off when adapting any technology in the classroom between the benefits obtained and the issues that are related to the implementation, usage and management of the technology. In this relationship between technological development and learning design, it is important to consider all the instances in which one aspect informs the other, and it is even more important to be aware of all the issues that arise when there is a mismatch between both approaches.

Available literature also shows a lot of instances in which a technological development was poorly received. Many studies pointed out the dangers and inefficiencies of a particular technology in learning scenarios, and it is possible to identify a push towards reconsidering the role of information technologies in the classroom (Bećirović, 2023; Boonmoh et al., 2021; Ifinedo & Kankaanranta, 2021).

The second area of motivation for WorkshopAR is to explore the synergy between the developer and the educator. Hopefully, the documentation of the design and development process followed for *WorkshopAR* provides valuable insight of the challenges of creating educative technology, to the point of becoming useful for future projects in similar scenarios. A good step forward from this research would be to polish the positive experiences and to discuss the negatives in future work.

Section 4.1 of this chapter will provide a general description of the context in which WorkshopAR was developed and the broad requirements that were identified. Section 4.2 will show a more detailed description of the use cases and scenarios designed for the tool and their relation to the overall research goals of this project. Section 4.3 is dedicated to the architectural design of the software, focused on the high-level decisions taken to accommodate the learning goals present in the development context and in the research objectives. Finally, section 4.4 offers a broad summary of the results obtained and the conclusions reached from the analysis process made throughout the chapter.

4.1 Project Description

Within the context of the Industry Project course (also refered in this document as ENBU79X/89X), the objective is to analyse how students use AR technologies as an aid for the collaborative aspects of their projects. It would be of interest to identify what problems are the students solving or finding, how the technology shapes the structure of their work, the relationships

between peers or the development of their learning process. By comparing these observations with the behaviours of other students in the same scenario, it would be possible to identify key behavioural changes promoted by the implemented tool, opening the possibilities for further analysis and pathways for future development.

In general, the development of WorkshopAR aims to fulfil three main objectives, which are independent of the learning goals proposed by the case study context. These objectives will be labelled as Observation Objectives:

> OO1. Visualising my team. Sections 2.1.1 and 2.1.4 of the literature review exposed the challenges of teaching collaboration skills, and described the process in terms of the time, guidance, and exposure to proper tools needed to succeed. WorkshopAR is meant to use AR to graphically convey the information needed to manage a group, for establishing a discussion or for organising a conversation. The idea is to offer tools that convey a good grasp of who the group members are and what they are doing.
>
> OO2. Visualising decisions. *WorkshopAR* should provide the ability to show digital representations of the learning material and allow the user to hold a discussion around that. The discussion can derive in solidifying knowledge or building learning, or could help in managing decisions, debates with peers or giving a visual representation to the workflow followed by the group. It should be possible to determine from the observations if interacting as a group with a digital representation of the learning material promotes any change on how the group is learning, how the material itself is being used, or if the augmentation helps managing the learning activity or not.
>
> OO3. Augmenting the workspace. *WorkshopAR* was initially envisioned as a tool for presential collaboration with a physical shared space where the students are working. The tool should be able to use that space as an anchor for the visualisations and use the capabilities of AR to give extra meaning to that physical context, either by identifying and using elements of the environment in the augmentation or by adding digital elements anchored to the space that can help the user to create such meaning. In terms of research goals, observations should be able to identify if the ability to augment, visualise and customise digitally the physical environment of a group helps with aspects related to team identity, productivity or team management.

So far, these objectives are devoid of context. Their aim is to support the research questions proposed, especially SQ1 to SQ3. The objectives describe activities common in any collaborative situation, and the insights found in the case study can provide answers to questions related to the value of AR in education. The main hypothesis does state that AR offer advantages using clever visualisations and quick interactions with the context, and *WorkshopAR* is proposed to offer such scenarios.

4.1.1 Learning Goals

The Industry Project course focuses on developing crucial soft skills on students in the context of project development and management, emulating in different ways common processes and scenarios found on the construction industry. In general, the learning goals can be enunciated as:

1. Develop, document and communicate the design, plan and cost estimation of a construction project, considering the expectations of the client and the limitations exposed by the context, relevant policies and local constraints.

2. Participate in and contribute to the project as part of a team, considering the expectations of the role as well as the processes and tools agreed upon by the group.

3. Create and use the proper tools to communicate decisions to the client, report progress, receive feedback and ask for information.

The expected learning outcomes of the course highlight teamwork and communication, and as such, the intervention designed around *WorkshopAR* should focus on identifying the tools that AR technologies can provide to facilitate or boost that collaborative process. The aim should be in facilitating group management, communication among members and aiding in the production of knowledge and materials for the project.

The guiding prompt of *WorkshopAR* is to provide students with a digital environment that helps in visualising the activities performed by the team and to highlight possible tools at their disposal for proper team management, discussion of ideas and effective decision making.

By aligning these goals with those of the course, *WorkshopAR* can provide a tangible feel of abstract concepts used in team management like participation, ideas and task allocation. It can also reinforce in the students the need to develop a strategy to deal with issues related to groupwork. It can also prompt ideas about self-reflection, evaluation of performance and the development of each individual role inside the group.

The main goal can also be aligned to research questions SQ1 through SQ3. The case study around the course provides an ideal observation environment to compare different approaches to collaboration, not only with those using AR or not, but also behaviours related to the use of different types of technologies and to the circumstances fostered by the design of the course.

Since the case study is complex and strongly based on observations, three scenarios have been selected to focus the development of *WorkshopAR* and to simplify and direct observations, comparisons and analysis, making the data gathering process manageable for the timeframe of the research.

These scenarios represent the general framework used to provide context to more specific and goal driven use cases in the future, which will be exposed in Section 4.3. The scenarios are born from the learning goals of the course but not necessarily from the particularities of its development. They represent common instances of collaborative work and common roadblocks in the development of effective teamwork (see Section 2.1.4). A deeper analysis of the implementation of the tool is described in Chapter 5, and a description of the changes

and adaptations needed to properly incorporate *WorkshopAR* as part of the observed cohort can be found in Chapter 6.

Scenario 1: Team Management

The first scenario is about tools that can be used to manage the composition and dynamics of a group and to help in answering questions like: Who is my team? What are their roles? What is my role? (Bannister et al., 2014; Delgado Piña et al., 2008).

The proposal is to use visual cues and digital constructs to represent information about team members and their work, offer the means to interact with such information and to share it with others. This *digital profile* can help students to start a conversation around the structure of the group and the evolution of the dynamics of its members. The same reasoning can be applied to give a visual anchor to the tasks allocated and the roles assigned.

A specific manifestation of this scenario is the first contact the members of the group have. *WorkshopAR* can help in that first process of identifying who is who, to create the proper environment dialog and to establish the first rules of communication. It can also be extended to scenarios such as a new member trying to integrate into the group or as a management tool to experiment and consolidate the group's structure.

WorkshopAR can also provide a digital presence for the team itself and represent information about the work being done and who is doing it. This digital presence can be defined in terms of the physical space where the group is meeting. This will serve as the positional anchor for all the digital constructs that can be used as part of the team's activity. A digital room can be created for the team members to enter or connect which would signify the disposition to start working. The room will be constrained or superimposed to the physical space where the group is gathered and can be composed by the digital constructs the team is using to work and all the physical elements the application could recognise.

This is a good moment to explain the first design constraint taken for this project. *WorkshopAR* will provide support only to face-to-face collaboration. Online or asynchronous collaboration won't be considered.

Sections 2.1 and 2.3 of the literature review exposed the importance of network technologies in the analysis of CL and the expansive field of online collaboration. The opportunities of exploring the connectivity capabilities of mobile devices as part of AR application was also part of the discussion, and a big focus of this development is to explore such possibilities and to leverage the ubiquitous connectivity offered by mobile devices to power seamless connectivity between users.

It is also true that this research wants to understand the unique capabilities provided by AR technologies in terms of augmentation of the physical space, a scenario that adapts easily to face-to-face interaction and connectivity with users in proximity. This does not mean that such elements cannot be together with online interactions, but they do add another degree of complexity to both the research and the development of the software, risking the possibility of taking the spotlight from the main objective of understanding CL and the influence of AR in the process.

To conclude, Scenario 1 proposes a solution in which the team and each of the team members have a digital profile that can be interacted with. The information in the profile can be used as the main anchor for the software to provide the visualisation and augmentation

tools that aid in the process of team management, communication, roles, task allocation and team structure.

A visual representation of all these concepts can be seen in Figure 4.1, where the room represent both the physical space used by the group to work and the current instance or session the group is participating in. The room will hold all the digital objects used during the session as well as framing all the other activities the team can perform.

Scenario 2: Work Session Management

For this scenario, we can define a work session as an activity the group decides to execute for a given time with a set of goals in mind. It can also be described as the group members participating in a lesson or a learning activity. The session would be composed by participants, the space the session is taking place in, and the goals proposed.

It is envisioned that *WorkshopAR* can provide tools to identify and manage aspects like:

- The participants in the work session.
- Status of the session.
- Current objectives and the status of those objectives.
- The resources at hand for the session.

Scenario 1 is about giving the room a digital representation that can be interacted with. Scenario 2 uses those elements to construct a digital representation of the work session, as shown in Figure 4.2. The participants will connect to an active room in which a session is taking place. The room will be associated with a set of goals, active resources and a physical space to which is anchored.

The second development constraint that can be analysed at this stage is related to resources. Ideally, WorkshopAR should be able to provide or interact with all the resources the group needs to perform their work. In just the context of ENBU79X/89X, the list of available resources could comprise elements such as:

- Tools for creating documents and presentations.
- Tool for architectural design and analysis.
- Spreadsheets for calculations and project management.
- Visualisation of documents and design proposals.
- Tools for digital modelling and design.

It is not feasible for the scope of the development to consider all the possibilities. Seamless interaction between tools is a valuable quality functionality but would not add significant insight into the research goals at hand. In contrast, observing how the students interact and integrate all the technological tools at their disposal, and how they evaluate their usefulness and functionalities, does align with the observation objectives of the research, providing

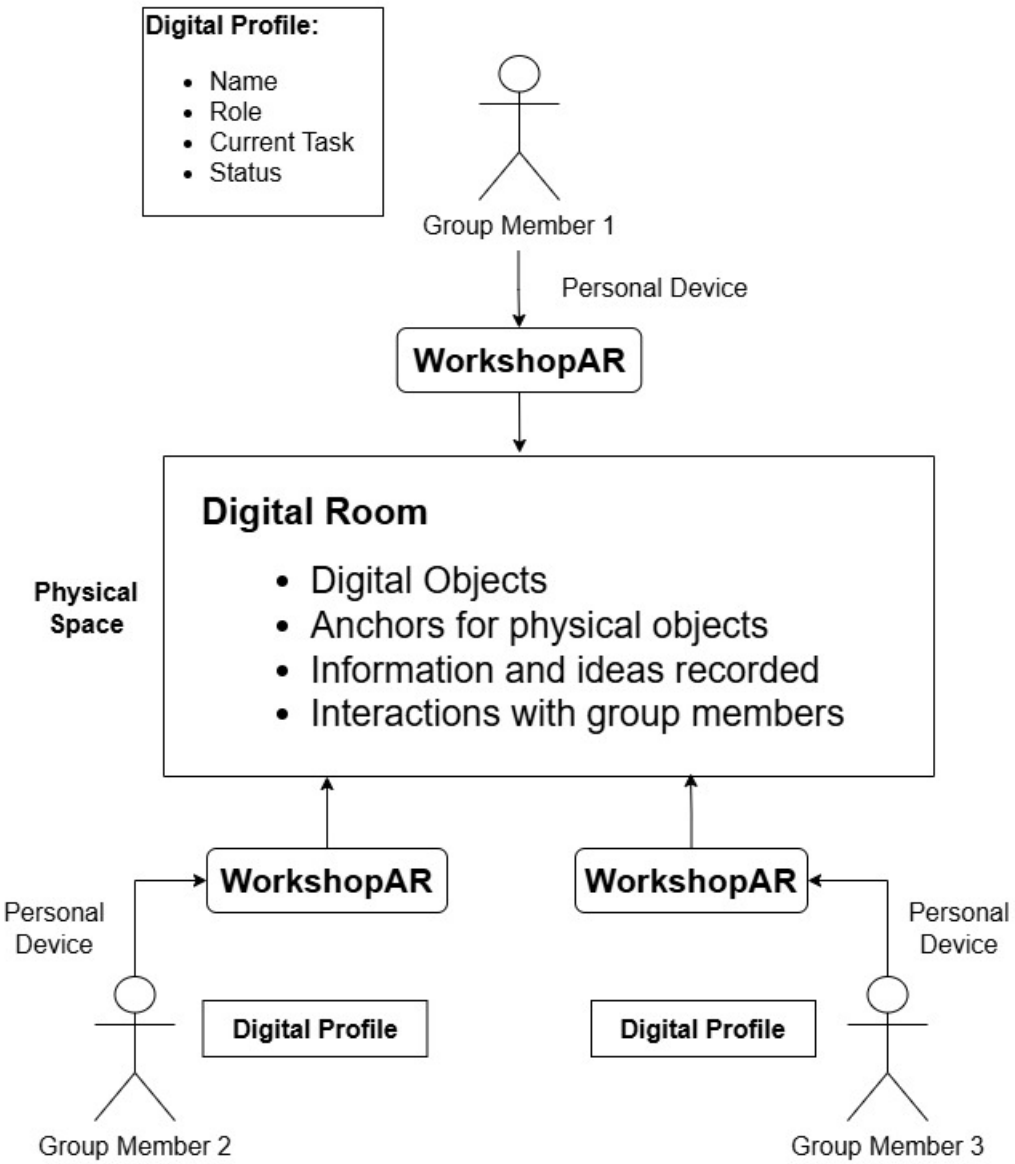


Figure 4.1: Team Management Scenario

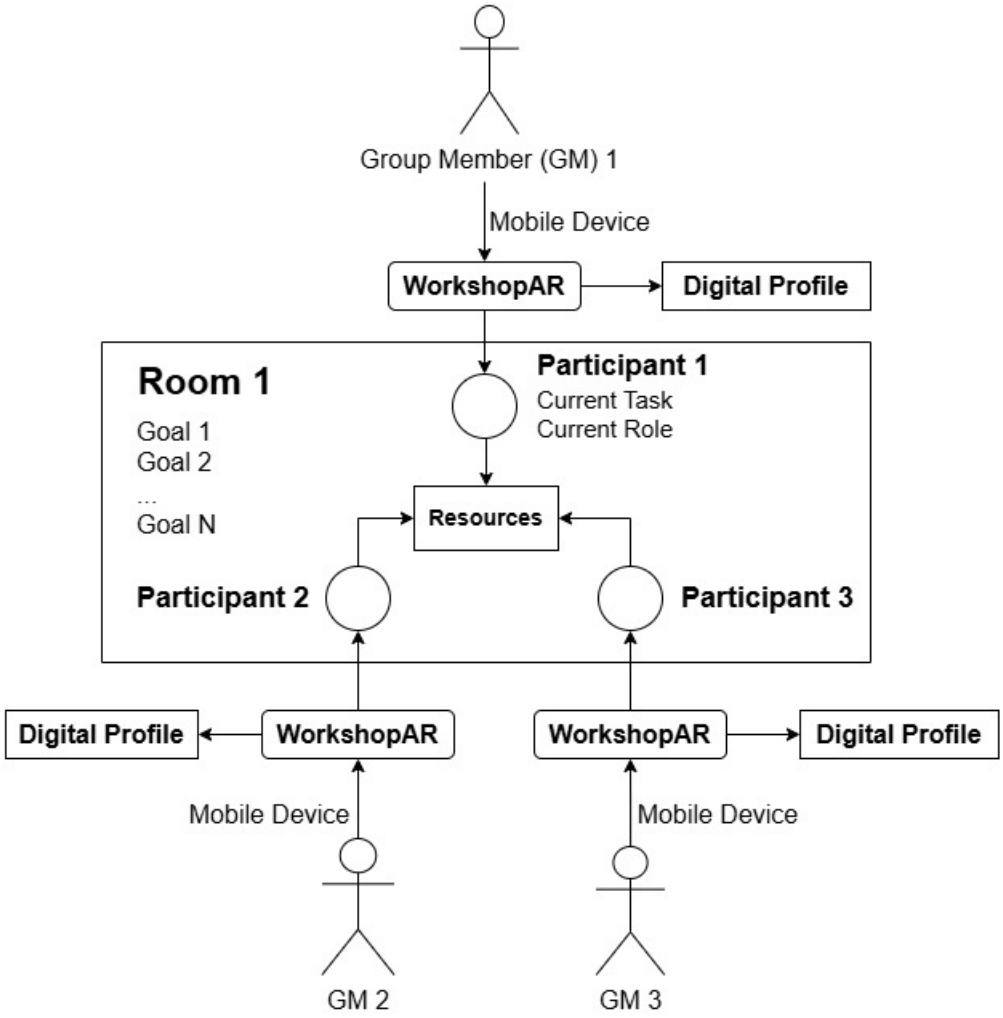


Figure 4.2: Work Session Management Scenario

insights for questions SQ4 and SQ5, which are trying to identify the specific value of AR in learning scenarios, especially in comparison to other tools.

WorkshopAR will be limited to two resources that can be used as part of a working session:

1. Visualisation of and interaction with simple digital models for planification and discussion.

2. Anchoring data or information to a digital object or physical space.

These two resources offer general help for the most common activities of the course: proposing solutions to the spatial design of the project and organising discussions around such proposals. The purpose is to analyse how the students change (or not) their approach to collaborative work when they have access to more tangible representations of abstract concepts such as ideas, proposals and discussion, and how (if at all) the discussion is affected by the ideas being more visually anchored to the real world.

Scenario 3: Discussion and Debate Management

Scenario 3 is related to the activities that can be performed during a work session but that are not part of the team management. *WorkshopAR* aims to offer tools for discussions and debates around the work done by the group and the decisions being taken. The tool can give visualisation and structure to elements like:

- The object of debate or discussion.
- The structure and flow of the discussion.
- The responses and ideas generated.
- The active participation of different team members.

The proposal is that AR can offer a visual anchor or structure to the process, helping students in understanding it and managing its flow.

To summarise, the three scenarios presented above illustrate the main learning objectives guiding the design of *WorkshopAR*. The objective is to provide a tool that helps the students to identify and structure the most relevant aspects of their collaborative work such as team management, work management, communication and decision making.

4.1.2 Development goals

It is also possible to identify a set of points related to the technological and software development of *WorkshopAR* that are worth analysing and that can offer insights on how the technology influences the achievement of the learning goals. Some constraints in the development process can also be discussed related to issues highlighted in this section.

The first development goal is concerned with the multi-user AR experience. This requirement implies some form of network infrastructure to support several users interacting at the

same time, sharing resources and visualisations. Thanks to the information provided on the descriptions of scenarios 1 through 3 in the previous section, it is possible to summarise the main extent of the networking development into the following objectives:

- Provide a lobby-like architecture for connectivity, allowing users to connect in and out of a work session in a seamless way.
- Share and synchronise information about the digital profiles of the team, the room and the resources being used.
- Share a synchronous interaction with the digital objects used and the augmentation created for the work session.

The main proposal of the research is not the software solution developed, rather the interaction design engineered to fulfil the networking requirements and the process followed to integrate the solution in the flow of a work session, considering some important requirements imposed by the context of the case study:

- Offering a seamless connection with minimal or high-level configuration.
- Disrupting the work of the students as little as possible, considering they are contributing to a graded project that is part of their professional education.

The second development goal is to provide a platform-independent solution that can support a Bring Your Own Device (BYOD) approach to the implementation of technology in the classroom (Disterer & Kleiner, 2013). This considers that, in theory, the main platform for deployment of AR solutions are mobile technologies, an ecosystem that is ideal for BYOD initiatives (Imazeki, 2014; Väljataga et al., 2016) due to accessibility and ubiquity. Mobile devices also offer hardware solutions to several of the networking objectives proposed previously.

Additionally, a solution that is platform-independent can also aim to accommodate AR devices that are not based specifically on smartphones, such as specialised Mixed Reality (MR) headsets like the Meta Quest 3, Magic Leap or the HoloLens. This would create a challenge in design to adapt the control and interactions of the experience specifications that each participant has access throughout a session. Figure 4.3 shows a high-level architecture of a possible solution for this scenario, which is similar to other systems that offer cross-platform functionalities, commonly across a web deployment (Medvidovic, 2002).

Similar to the way in which systems like Netflix balance access to content depending on the device used for access ("System Design Netflix | A Complete Architecture", 2023), a general architectural proposal for *WorkshopAR* would consider an interface between each local participant and the shared interaction in the room. The interface can manage input interactions, data types and visualisation types before handling control to the shared room, and vice versa, handle responses and transform them to data that can be properly processed by every device connected to the session, akin to a system like Andrés and Pérez (2017).

With that analysis in mind, Chapter 5 will describe in more detail the reasoning behind not pursuing a full cross-platform architecture. In summary, the research value did not align

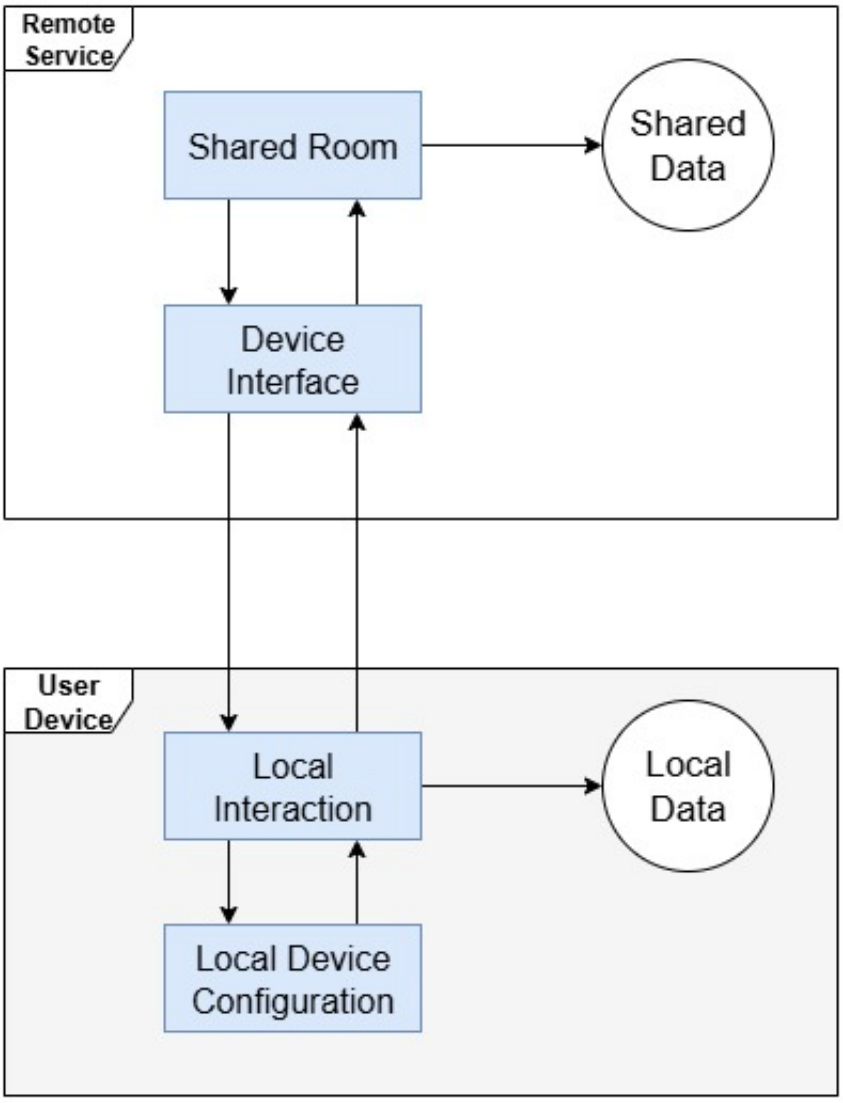


Figure 4.3: Concept of a Multi-Platform Architecture

properly with the value gained by this type of development. The BYOD approach was instead tested by focusing on mobile devices which, paired with other technologies selected for the development, already covered any mobile architecture using Android or iOS, offering a wide spectrum of devices available to the users.

The one element left behind by not pursuing a full cross-platform architecture was testing the integration of different means of interaction in the same work session. It was decided that, for the scope of the research, it was worth to focus first on other aspects of the development and probably relegate this aspect for future work. Nonetheless, the question of cross-platform will resurface in the analysis of the case study and during the user-centred design described in section 5.1.1.

In conclusion, the development of *WorkshopAR* proposes architectural and implementation solutions for a multiuser AR application deployed over cross-platform mobile technologies. These objectives provide opportunities to understand the technological challenges of implementing multiuser AR applications and how they affect and are affected by the learning goals proposed previously.

4.2 Use Cases

The scenarios described in the previous section represent the general goals for which WorkshopAR will be used as an intervention in a learning setting. To start the software design process, the first step is to identify and describe the specific functional requirements to be developed. The following section will describe the most relevant requirements identified for the research intervention of ENBU79X/89X. This information is going to be described in the form of use cases, or user stories, to emphasise three aspects:

- The general interactions performed by the users, not the particularities that have to be developed.
- The development goal being fulfilled by the use case, or at least any technological challenge that could be of interest for the analysis process.
- The learning goal being fulfilled and how it is related to the educational objectives of the research.

Before exposing the use cases, it is necessary to discuss some of the vocabulary that is going to be used in the descriptions. These are terms referring to common elements of the interaction with the app, the activities enabled by it and the resources used to create the experience.

A *user* is any student using the app. Every user has a personal profile that is shared between sessions. Although in the context of ENBU79X/89X all students belong to a particular group for the development of the course's project, the app is not going to enforce that organisation, and a user can become a participant in any session available.

A *participant* is a user that has joined a *digital room* and now is part of a *work session* with other users. As a participant, a user has a role and a set of assigned tasks, which are only valid inside a particular session.

A *digital room* is the space created by the app and used by the participants to hold the session. The room doesn't need to be a closed space. The app creates a *workspace* for the room and associate the session information to a room anchor, a digital object situated in the space selected.

A *work session* is the work done by the participants that enter a *digital room*. The session has a general goal associated, which can be modified and updated.

A *workspace* is a digital object representing a space in which the participants can position and interact with digital objects. In conjunction with the *room anchor*, it also creates a visual representation of the *digital room* in which the *work session* is taking place.

4.2.1 Create a Shared Digital Room

Description: A user must be able to initiate a *work session* by creating a new *digital room* for the group. The *digital room* is identified by a unique name and described by a set of goals for the session. The user can configure all these elements before launching the session. Upon opening the *digital room*, any other user can search the name of the room and join it, adding themselves as participants to the *work session*.

A *room anchor* will be added to the *digital room* which will present information about the *work session* upon interaction.

Development goal: The *digital room* represents the main point for the multiuser experience. All the participants in the *digital room* will share the same visualisations and will be able to interact simultaneously with the same digital objects. Ideally, the connection to the *digital room* is seamless, requiring only the initial configuration for setup and run.

Educational goal: The *digital room* will be linked to the concept of a *work session*. When a room is active it means that the group is working, and all the participants share a current goal. The *digital room* provides the students the opportunity to have a structured *work session*, and the digital markers used provide a tangible and interactable representation of the goal and the room itself.

4.2.2 Create a Shared Workspace

Description: Upon creating a *digital room*, a participant needs to define a space in the physical environment that will be used as the shared *workspace* for the session. *WorkshopAR* will identify suitable horizontal spaces like tables, desks or the floor, and overlay a digital plane over them. The participant can select one of the detected planes and modify it to convenience to suit the preferences of the group or the needs of the current session.

Development goal: The *workspace* will be the base augmentation provided by *WorkshopAR* to give a visual representation to the *digital room*. The *room anchor* gives basic information about the session, while the *workspace* facilitates the interactions with other digital objects, constraining the movement and location of all the interactive 3D models and providing a reference point for any other digital constructs.

Educational goal: The *workspace* gives a location for the shared resources of the group, elements that are public to everyone and could be used as inputs in each task. The *workspace* anchors all the digital objects to a common point and the group itself, creating a visual representation of the *digital room* while keeping the constrains of the physical space used.

These constraints are more malleable than in a normal room, and the group can use the digital elements of the app to explore or expand what is provided by the physical space.

4.2.3 Create a Profile

Description: A user can create a digital profile to use in a *digital room*. The profile is linked to the instance of *WorkshopAR* installed on their device. When not connected to a *digital room*, the profile consists of a preferred name and a colour that represents the user. When connected, a user can also be described by a role and a set of current tasks.
Development goal: The profile is a representation of the users in the when connected to a *digital room*. It also serves as an anchor for interactions with other participants and provides a form of digital avatar that carries the information of the profile.
Educational goal: The participant's anchor gives visual structure and prompts the discussion around different topics like team management, assigned roles and allocation of tasks.

4.2.4 Point to Something or Someone in the Digital Room

Description: This case is related to provide basic communication tools to the students, specially to convey information about the resources available and the users connected to the *digital room*. Participants should be able to specify the person or object (physical or digital) they are referring to in a conversation or instruction. This clarification in the communication process is going to be referred as *pointing*.
Development goal: This interaction is meant mostly for digital objects and has an important role in the multiuser experience. It is a simple tool to facilitate communication and helps to mitigate any ambiguity or confusion. It is also an interesting technical challenge to account for both digital objects and the physical context of the room.
Educational goal: This is a simple tool to promote and facilitate communication. It is one of many ideas to explore the concept of *augmented collaboration* by providing digital tools to visualise the communication process and analyse its impact in the behaviour of the students regarding learning, group dynamics and team management.

4.2.5 Check the Status of Other Participants

Description: A participant should be able to access information about everyone connected to the same *digital room*. This information is related to their profile and their status, described by their role, assigned tasks and participation state in the activity.
Development goal: The technical challenge of this use case is related to the way the information present in the profile can be transmitted and synchronised on the network, as well as the proper interaction methods to access it. These interactions can also be extended to accessing the information and current state of the *digital room*.
Educational goal: This is an opportunity to understand the role and influence of technology as part of the collaboration process. Ideally, the tool provides quick access to information about the current state of the session and the team members, but it could also become an unnecessary barrier for something that should be verbally communicated. It should be possible to observe how students use this functionality, how it affects different communication

processes inside the group and how *WorkshopAR* compares to other IT tools that mediate in communication.

4.2.6 Share and Pin an Idea

Description: A participant should be able to type an idea and pin the text representing it somewhere in the *digital room*, making it public and accessible to all the other participants. Similarly, a user should be able to see and interact with all the ideas pinned by them and other users.
Development goal: This use case also belongs in the *augmented collaboration* category and offers the opportunity to record and visualise ideas and information in the same way a whiteboard would do. This is a way to experiment with the idea of offering a relationship between the digital representation of the information and the physical space (Y.-H. Wang, 2017; Zünd et al., 2015). The objective is to prompt discussion, associations and structure to a conversation while sharing and recording ideas between participants.
Educational goal: In the same spirit, it is another tool to visualise and interact with information, making communication visible. The idea is that, by adding a relationship between the space of the conversation and the ideas proposed by the group it will open the possibilities to get deeper, different or more structured types of discussions.

4.2.7 Add and Interact with a Model in the Digital Room

Description: This interaction is related to simple digital models either build in external tools and imported to *WorkshopAR* for visualisation or built in the tool using simple construction blocks. Since the main objective of ENBU79X/89X is related to architectural design, this interaction with digital models is meant to facilitate communication and discussions related to this field. This communication can be centre d around collaborative creation of a design or discussing ideas, getting feedback or proposing changes. This use case considers all the interactions needed to add the models to the app, share them in the *digital room* and perform simple interactions with them like moving, selecting and transforming (e.g., moving, rotating, scaling) the models.
Development goal: More than a technical challenge, the focus of this use case is on the interaction design needed to propose a solution. For one, there is an interesting opportunity to analyse the design and usability of the interactions needed for this task, considering that the app will use a mobile phone deployment. A set of conventions in interaction and visual language are expected for both the selected hardware and the AR nature of the tool, and it is important to analyse those conventions, implement them, expand them or revaluate them if needed.

Second, this interaction must consider the multiuser scenario of the project and the necessity to coordinate interactions of shared objects over the network. Although the technical implementations of these requirements are interesting, it is more important for the research goals to observe how the user experience proposed forces or promotes different behaviours in the users, and how those behaviours affect the learning and collaborative processes.

Educational goal: The interaction between participants is again the focus rather than the activity itself. Since the main objective of the course was design and construction planning, it was considered interesting to provide a flexible enough interaction that promoted discussions around different elements of the design process and the ideas proposed by the students around space and structures. The building blocks metaphor was chosen to promote a visual and physical anchor of those elements of the architectural design as part of the AR experience.

A more explicit goal for the development of this functionality is to organise and structure the work of the students around digital and physical tools that boost the idea-discussion-decision loop with AR and communication technologies. This is, again, guided by the principle of augmented collaboration.

4.2.8 Participate in a Debate or a Vote

Description: A participant must be able to propose or be part of a group vote or debate. Both cases will be defined as instances in the *work session* in which the input of the participants is needed to take a decision. A vote is a decision to be taken among a possible group of options, while a debate has an open input nature.
Development goal: This is an interaction design that allows the users to visualise in the augmented space all the elements taking place in the decision-making process. This idea explores possible implementations for the tool to manage a debate and to storage, compile and show the results of the activity.
Educational goal: This use case reinforces the most prominent activities in which communication skills are developed thanks to the classroom groupwork. *WorkshopAR* is not expected to be used as the sole manager for the communication and planning needs of the group, as other tools probably already fulfil those roles. The idea is to offer a different approach to the communication interactions that happen when taking decisions, specifically in face-to-face scenarios. This type of discussions is prone to be more informal, unstructured and with no archive of the activity itself. Once more, the aim is to offer a different type of solution based on visualisation and context augmentation.

4.2.9 Pause the Current Participation

Description: A participant should be able to signal the group that he/she is not actively participating in the session and that progress in the current tasks is in pause.
Development goal: The reasoning behind this use case is to create a distinction between the physical presence of a participant in the *digital room* and their activities in the group, giving more depth to the status of a participant, also helping to visualise and symbolise some social cues that are hard to verbalise. In a more technical sense, it is also a function that helps in pausing the use of the device without finishing the session.
Educational goal: This option is the best example of a tool for group management that has more significance than simple actions like checking a list of participants or managing access to the digital room. This functionality aims at giving visual presence to the work of the user, to establish boundaries, proper communication habits and prompting discussions around time and space management.

4.2.10 Conclusions

The exposed use cases represent the most important functionalities that *WorkshopAR* should be able to fulfil to provide insights for the research goals of the project. These scenarios present the most common instances in which the students can develop collaborative skills or in which their collaborative work is the key aspect of their work. These actions include diverse aspects of activities such as team management, task planning, effective communication and decision making.

The main proposal that this software development is meant to explore is that through AR it is possible to create a visual representation of the work that the users are doing and of the resources in use. The plan is to design simple interactions that create a relationship between the ideas explored with the tool and the collaborative skills that the students need to develop.

The plan also relies on offering the proper environment to think or discuss issues around the structure used to work and plan, rather than to force a specific way of working. This approach can create the opportunity for students to reformulate their current way of working and find alternatives that incorporate new information into their processes, but it can also cause the students to completely ignore the tool.

This is an acceptable risk scenario. In first instance, it creates the least amount of friction with the teaching approach of the course, giving the students a technology that they can freely use to enhance their work, and not a forced experience they could resent or that can even inhibit their work. It was decided that a free exploration of the tool offered a better and healthier experience.

It is also acceptable in terms of the research goals. A scenario in which a group did not interact with the tool also offers interesting insights. Paired with the case study, a failure engagement with *WorkshopAR* can elicit questions regarding the tools that the group is using for communication and planning, how the group is structuring their work and managing their time, among other possibilities. Answers to these questions can help in constructing an interesting case study.

4.3 Architectural Design

The following section will discuss the main ideas guiding the architectural design of *WorkshopAR* and the reasoning behind the decisions taken. The whole process ill be described using the most important quality requirements identified for the development of the tool, the most important functional components designed, and the available frameworks and technologies selected to help in the construction of the tool. For this purpose, several architectural and structural diagrams were created to explain and visualise the design decisions taken and the software architecture discussed throughout this section.

A common visual language was used that loosely follows the structure and rules proposed by UML, but it was not strictly followed nor are any of the diagrams in this section UML-compliant. The main objective was to offer a quick visual representation of software components and behaviours that facilitated the communication of concepts and the discussion of the decisions taken, while keeping the diagrams simple and easy to read. The main rule was

to keep consistency between diagrams, especially with colour coded information as follows:

- Grey elements represent hardware and devices, physical instances where software is deployed.
- Yellow elements represent software components, entities or a set of entities that have a common purpose and functionality. They could be zoomed-in for more detail, but that is not necessary to understand the idea conveyed by the diagram overall.
- Blue elements represent more abstract entities, either because they represent big complex functionalities which serve several purposes or because they represent a state or logical concept in the execution of the software that is achieved by the interaction of several other components. As with yellow elements, the component can be described in more detail, but it is not important or necessary for the purposes of the diagram.
- Green elements are specific instances of an object (a class or a game object in Unity) used to show the composition of an important scene or the flow of data in a use case scenario.
- **White** elements are used for data or information being used, created or transmitted between other software components.
- **Arrows** are used to signify relationships and associations between components, or messages sent from one component to another, depending on the context of the diagram.

4.3.1 Quality Requirements

WorkshopAR is a prototype that helps in promoting proper work habits in the students for communication and collaboration. Independent of the specific functionalities to be built, the software needs to achieve these objectives through the architectural design proposed:

1. **Multiuser interaction:** *WorkshopAR* is a cooperative experience for the synchronous interaction of small groups of 2 to 6 students. All the participants in the interaction will be present in the same physical space and will share the same digital augmentation of the environment, but with different points of view and instances of interaction. Digital objects in the space will also be shared and interactions with them must be synchronised and coordinated between users. The participants will have a digital presence in the shared environment that can also be interacted with, and that interaction also needs to be synchronised and coordinated.
2. **Multi-platform deployment:** To support a BYOD approach, it is necessary to build a solution with a multi-platform deployment. *WorkshopAR* must work independent of any specific mobile platform and aim for the most common AR capabilities of devices currently in the market. Ideally, the tool should also support any other AR capable device, specifically, headsets available in the market like HoloLens, Magic Leap or Meta Quest 3. This implies that the tool must consider all the diverse input methods

available, display varieties and processing capabilities, and coordinate them within the shared experience.

This idea can be also expanded to a multi-role interaction, in which the activities are taking place in a room, consider different roles that any participant can take, and tailor how the user sees information and participates in the experience in accordance with that role. Different roles also open the possibility to interact within the room through mediums that are not necessarily AR.

3. **Spatial interactivity:** Due to the multi-platform approach taken and the irregular nature of the AR capabilities found in current available devices, it was necessary to make decisions about the minimal capabilities needed for the AR experience to function across different devices. It was decided that the core experience was in the augmentation of the communication process, and the relationship built between the group and the *workspace*. It was necessary to identify minimum features common in most devices and decide which aspects of the experience could rely on the available technology and tool, and which needed a solution through a more complex development.

The following quality requirements are not directly related to the outcomes needed for the research goals but are equally important to support a good development flow or to accommodate the particularities found in the execution of the case study.

4. **Flexibility:** Given the interactive nature of the development proposed and the exploratory approach of the research, the general component architecture of the tool needs to be as flexible and decoupled as possible. Particularly, it is important for the input system and interaction methods and processes to be easily swappable without affecting the core functionality of the software. These are the most fluid elements of the design, and from the very beginning, they are meant to be part of the main experimentation with the software. A flexible approach is necessary to facilitate testing and different ideas and approaches.

   Solutions related to the network communication and the creation of a shared space also needs to be flexible. Ideally the main utility of the tool is independent of the networking architecture.

5. **Extendibility:** Independent of the differences between the design and the implementation, component development will aim for cohesion and extendibility. The purpose is to support a small and incremental development that is easy to extend into full functionality over time. This will also support the user-centred approach proposed, where the users can experiment with a simpler version of a functionality, provide feedback and incorporate that information in the extension and refinement of the functionality.

6. **Easy-to-learn:** One of the core issues identified in section 2.2.3 in the implementation of AR in classroom is the all the extra time needed for students to learn the proper use of the tool. Lessons and plans had to accommodate, sometimes unsuccessfully, enough time to teach how to use the tool, coordinate its use in the planned activity and solve issues appearing when mishandling the tool.

This issue is a complicated task worthy of its own focus research. The design of *WorkshopAR* can leverage the common knowledge that students possess of their phones and the common interactions with them to propose interactions that emerge from the natural use of the technology. This can be achieved by exposing the users to small samples of the software and incorporate a systematic analysis of their feedback in the design process.

It was important to follow a formal approach to the analysis and development of the easy-to-learn design, taking decisions based on principles found in the literature and approaches proven successful in similar scenarios. The most relevant guiding principles are based on the work of Wigdor and Wixon (2011) who state that a design based on natural interaction is characterised by:

- The feel of a natural extension of the body.
- Offering the same natural experience for novice and for expert users.
- An experience tailored for the medium (mobile devices), not a mimicry of the real world.
- The proper use of context, previous knowledge, metaphors and input/output devices.
- Using paradigms when needed but not being afraid to ignore them.

Other ideas were summarised from works like Good et al. (1984), Macaranas et al. (2015), and Strijbos et al. (2004) that state general good approaches such as:

- Test different metaphoric mappings depending on the content of the interaction.
- High usability is achieved through careful analysis of feedback.
- Manage and consider user's expectations and knowledge.
- The changing expectations of the participants depending on the context of the experience and the tools available for the interaction.

4.3.2 Technological Frameworks

A set of tools were selected to implement current available technologies and frameworks to simplify the constructions of the basic functionalities of the application, support the solutions for more complex problems and provide a pipeline for testing and deployment. The tools selected helped in the implementation of basic AR functions and worked as stepping stones for more complicated interactions, for the networking development and for the multi-platform deployment.

The Unity engine was selected as the main building platform. Similar to other tools and environments like Unreal and Godot, the initial use case of Unity is in the development of videogames, but the tool can also be adapted to be the engine behind any type of multimedia

interaction software (CodeMonkey, 2024; Hussain et al., 2020). Unity was selected due to convenience and to leverage previous expertise with the tool.

Unity was used to handle the implementation of digital content and the interactions with it. Unity also helped in the management of diverse input methods and the multi-platform deployment of the software. Some of the issues related to networking were also solved using the Netcode utility. This package allows for basic network configuration and provides a framework to communicate information or to coordinate states of the objects across a network.

Finally, one of the biggest advantages of using Unity (and other similar tools) is that it provides an implementation of the OpenXR framework ("OpenXR - High-performance access to AR and VR —collectively known as XR— platforms and devices", 2016). This framework is and open-source implementation that abstracts into a common language all the specifics of different Virtual Reality (VR), AR and MR devices in the market. OpenXR provides a platform-agnostic implementation of different features like tracking management, display, environment tracking, input handling, among other things. This is a useful tool that helps in maintaining a single code base for the application and easily deploys it on different platforms at the same time. The project can then focus on solving specific problems without having to deal with issues at the hardware level.

Additional to the tools provided by the Unity engine, two other frameworks were integrated to the development to help with functionalities related to AR and the shared interactions in the network, as described in the following sections.

ARFoundation

ARFoundation is an implementation by Unity that provides a similar level of abstraction as OpenXR but specifically tailored to the AR environment and the mobile devices ecosystem. This is an important tool that helps in dealing with the most important frameworks in the market for AR development: ARCore and ARkit for Android and iOS devices respectively. These two frameworks cover most of the mobile devices available in the market, while more specialised technology uses APIs or frameworks that are either a derivation of the two main ones or can be handled with the OpenXR framework.

ARFoundation strongly influences the architecture of *WorkshopAR*. ARFoundation provides a set of manager utilities that act as a front-end configuration for several common functionalities of AR such as image processing, feature detection, point-of-view tracking or image composition. The managers communicate with a series of subsystems that abstract the specific hardware implementations of ARCore, ARKit or other similar toolkits. This means that all the functionalities of *WorkshopAR* are built by coordinating the managers provided by ARFoundation with the proprietary code developed for the application. Additionally, any implementation communicates with the hardware layer via the subsystems available, allowing the creation of a single code base for every platform. Figure 4.4 shows the component architecture of *WorkshopAR* when deployed in a generic mobile device, differentiating between the code found in the core Unity implementation vs the local toolkit used to provide AR functionalities in the device.

This solution facilitates a deployment that is, at least in theory, independent of any platform. In practice, it is not that simple. It is possible to support any mobile device that implements ARCore or ARkit, and there is also the possibility to deploy in any other

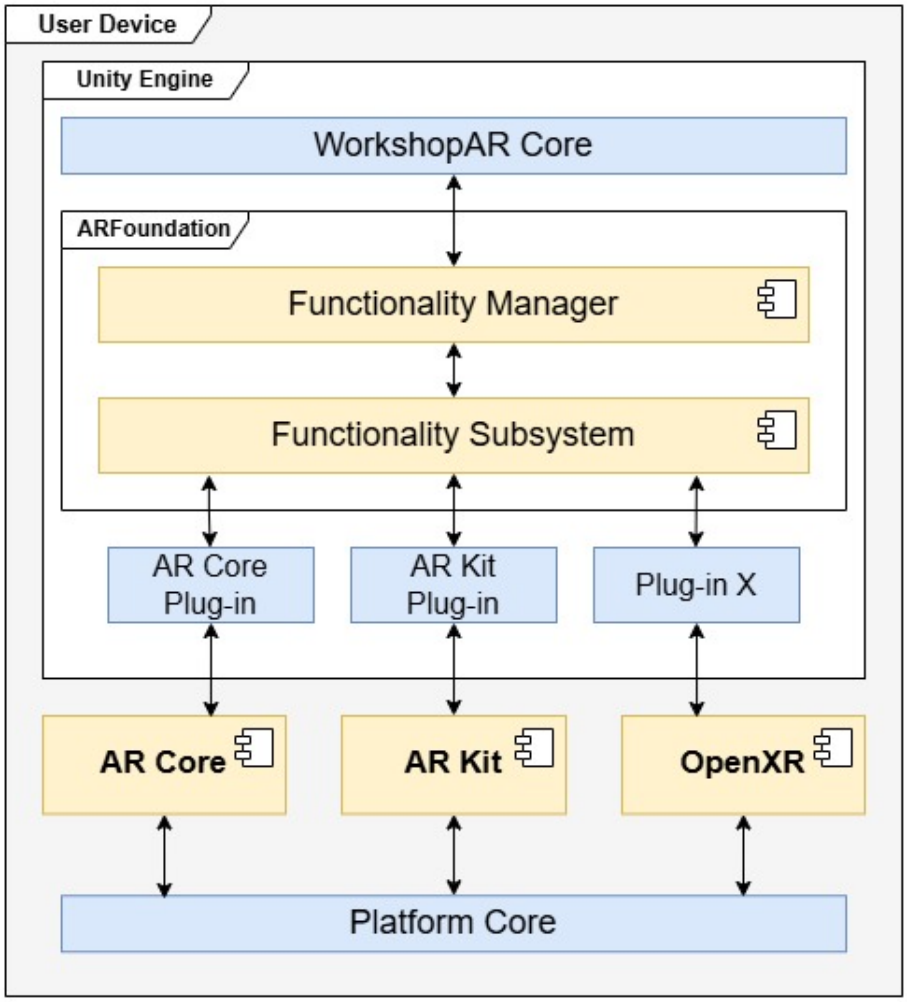


Figure 4.4: Integration with ARFoundation

AR-capable device if there is a subsystem in the ARFoundation toolkit that supports it or if the device supports the OpenXR framework. The problem is that all these implementations do not communicate smoothly, and to support a proper platform-agnostic single code base, it is necessary to identify all the intended platforms that are going to be used and coordinate all the low-level communication elements of the code to properly function. Other element to consider is that if used as-is, ARFoundation only offers functionalities exposed by the managers, which can obscure more updated versions of the lower-level systems or not show them at all.

Lightship

This component is part of the Niantic Spatial SDK suit ("Niantic Spatial", n.d.) and the set of solutions present in the Shared AR product ("Shared AR", n.d.). Niantic has pioneered the commercial use of AR in mobile environments through successful implementations in entertainment, educational and industrial contexts (BowTiedRobin, 2021; L. Lee, 2022). The SDK offered through Niantic Spatial is a set of solutions compatible with most development environments to create and manage complex AR interactions like life meshing, semantic detection, complex image recognition and networking.

For the development of *WorkshopAR*, the component integrated into the architecture is Lightship, a tool for the creation of shared AR experiences without the need of a complex backend network infrastructure. This tool is meant for small scale connectivity, supporting up to ten concurrent users. Lightship eases the development of the multiuser requirements and offers a scalable and flexible architecture that can be expanded and build upon in future work.

In isolation, Lightship works by using a simple client-server architecture. Any instance of Lightship can be connected to another one through an internet connection if they are using the same application ID. The architecture allows for the implementation of a dedicated server that controls the experience or for a distributed connection with one of the client instances acting as a host. At the network level, it is possible to use any tool at the developer's disposal, abstracting as much as possible the connection with the transport layer.

At the application layer, Lightship provides three important concepts to manage the shared interactions:

- **Room:** Parallel to the concept of a *digital room* provided in the use case definitions, Lightship defines a room as an abstraction for the main connection point for the users that are going to share an interaction. A room is identified by a unique ID within the rooms created for a unique application ID. Any client can see and connect to all the rooms available for that application. The rooms are created and managed by the service itself. They are hosted in an infrastructure provided by Niantic and can only be configured via the functionalities exposed in the SDK.

- **Shared Origin:** To create the functionality of a shared AR space, a host client first needs to create a room by providing an ID, configuration data and a point in space relative to the client that is going to be used as the origin point of the experience. This point can be obtained in different ways: image recognition, spatial features recognition, the relative position of the device or geospatial localisation. Upon connection with

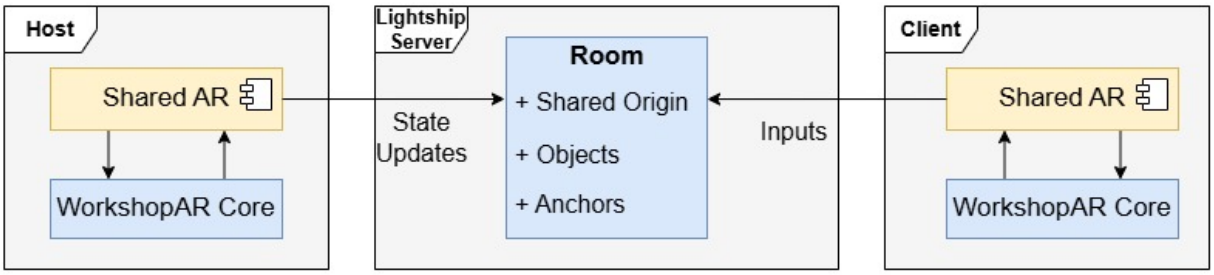


Figure 4.5: Integration with Lightship

other clients, each instance of the shared space is coordinated through the network using the shared origin. If a new object is added to the interaction, its position is always relative to the shared origin and coordinated through the network.

- **Anchors:** As optional additions to the shared origin, the host or the clients can create (if the deployment platform has the capabilities) detected features in the real space as anchor points. An anchor can be used to provide visual reference points in the space to maintain a smooth AR experience, especially when a lot of movement and points of view changes are expected, or when the network connection is not stable. An anchor is also shared through the network and helps in stabilising the room and the different points of view.

It is easy to integrate the main architectural points of Lightship into the architecture of *WorkshopAR*, mirroring the use of rooms to signify the connection of users to the group, the detection and analysis of features in the physical space and the coordination of data between interactions. The architecture proposed by Lightship also provides a simple and transparent networking component that allows a seamless connectivity on the side of the user with an easy process and minimal configuration, while also allowing the developer some control over the process. Figure 4.5 shows the architecture of the shared space as integrated with the core elements of *WorkshopAR*.

There is no necessity to go in deep detail about the general architecture of Unity as it is an extensive topic outside the scope of this document that offers little value to the research. Suffice to say that Unity encourages a modular component approach based around a core engine in charge of the coordination of resources and the communication with the local device. More information can be found in Messaoudi et al. (2015).

As for ARFoundation and Lightship, Figure 4.6 shows a relational model among their most important components, the core development of *WorkshopAR* and the external elements that interact with the frameworks in the execution of the experience.

4.3.3 Component Architecture

WorkshopAR uses two major components in its architecture: the *Session Manager*, in charge of the flow of activities in a single session for one participant, and the *Tracking Manager*, in charge of managing the AR interactions. Additional components are added to manage profile data and UI interactions. *WorkshopAR* relies on the Unity engine framework for

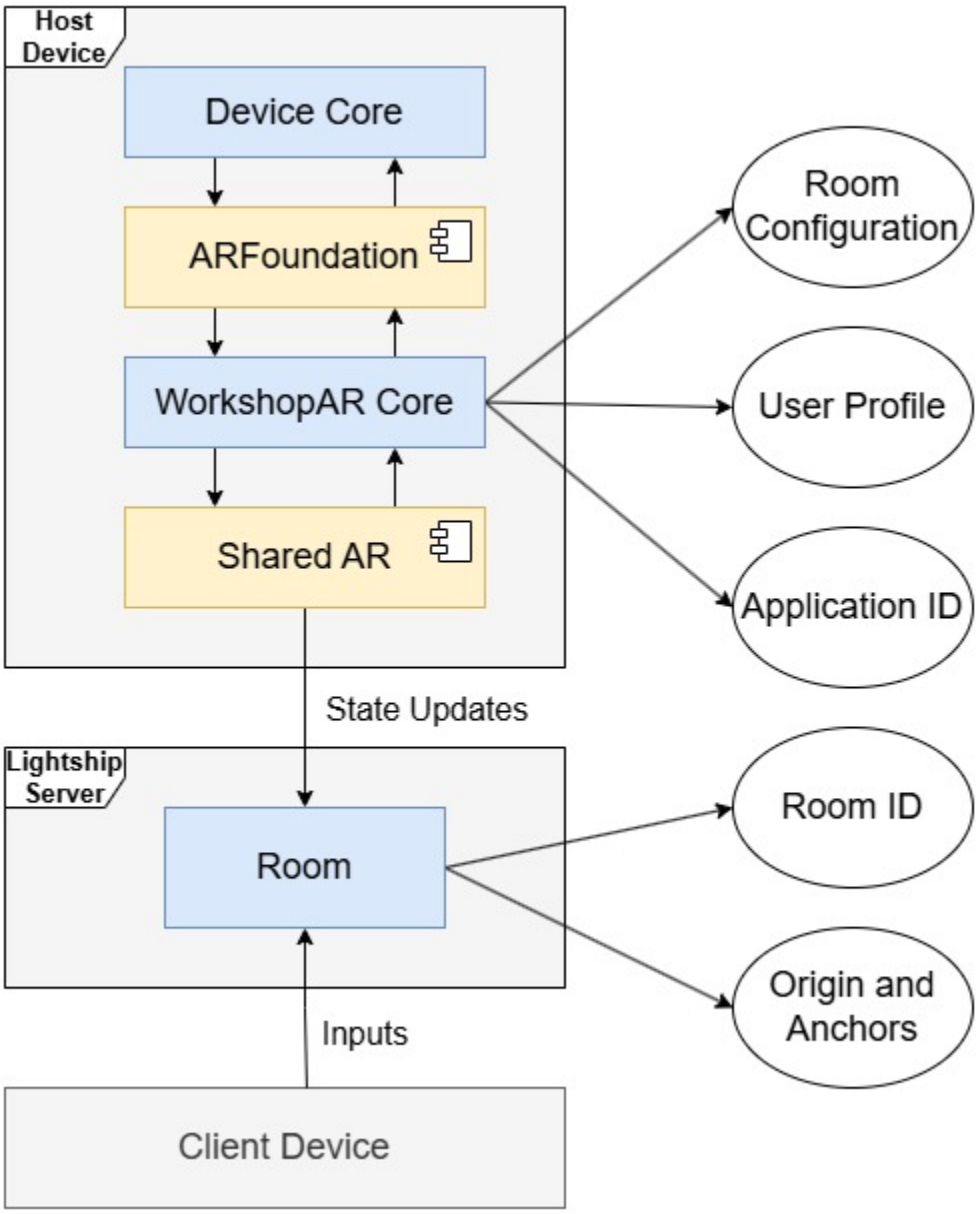


Figure 4.6: Relational Model with External Frameworks

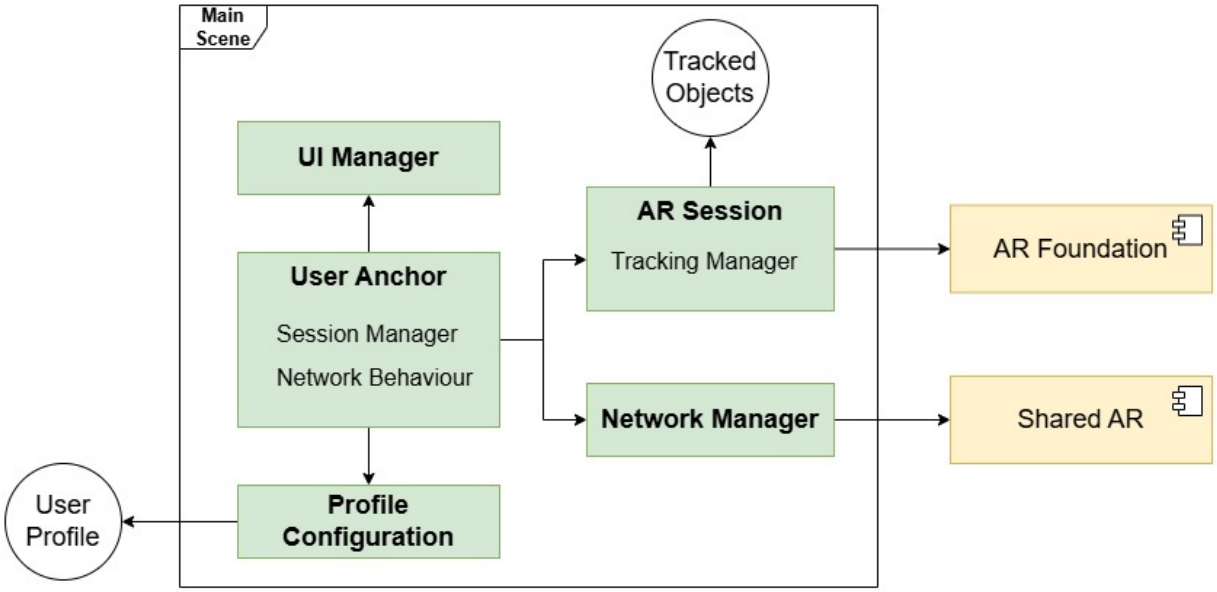


Figure 4.7: Unity Scene Relational Model

deployment in mobile devices, on the ARFoundation package to communicate with the local implementation of AR and uses Lightship in coordination with some proprietary Netcode development to create the shared room and to coordinate interactions.

WorkshopAR follows the recommended architecture for general Unity projects, in which the experience follows the execution of one or more scenes which in turn are composed by a set of game objects. Each object has a specific behaviour determined by its interaction with the engine, other objects and the actions scripted by its modular components. Following this architecture, *WorkshopAR* creates a *work session* for the users and manages the tracking of all the AR elements through three main objects in a single scene:

- The *User Anchor* acts as the visual representation of each participant in the *digital room* and the main control point of each individual action through the *Session Manager* component.
- The *AR Session* is part of the ARFoundation implementation and provides all the AR functionalities to integrate the scene with the camera image captured in the deployment device as well as the detection and management of features in the real space.
- The *Network Manager* helps with the implementation of Shared AR and manages all the Netcode used to create the shared experience.

Other objects are part to the scene to facilitate the visualisation of UI elements and to manage local data. Figure 4.7 shows a relational model of the previously described elements in the scene.

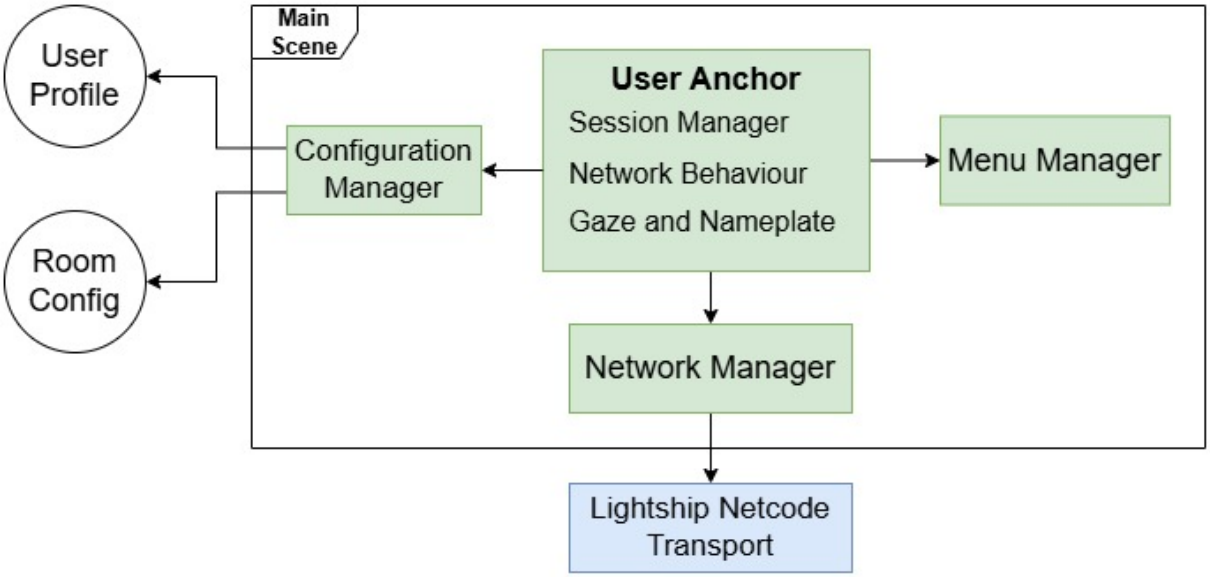


Figure 4.8: Session Manager Relational Model

Session Manager

The architecture of *WorkshopAR* divides its functionality into two parts: the collaborative session and the AR tracking. The *Session Manager* is in charge of coordinating three elements of the experience: access to the local profile of the user, configuration of the shared room, and coordination of interactions with the room and with other participants through the network. Other less prominent components are used to provide networking functionalities not managed by Shared AR as well as the interactions with the UI. The component functionality can be overall described by the following process:

- Get the local user profile.
- Configure the connection to a room.
- Coordinate network behaviours to fulfil the different interactions.
- Coordinate interaction calls through the network.
- Coordinate local interactions with the necessary data to show in the UI.

The *Session Manager* is also associated with the *User Anchor*. The Anchor is the visual and logical representation of the user in the room and provides different behaviours that show a visual representation of the user profile (position, name, current task, role) and social cues such as emotes and the user's gaze direction, all meant to be visual elements for the augmented collaboration design. The *Session Manager* coordinates the creation of *User Anchors* in the network, bridges local data between users and controls the flow of the session. Figure 4.8 shows a relational model of the most important components involved with the *Session Manager*.

Tracking Manager

The *Tracking Manager* is part of the AR Session game object in charge of controlling the visualisation of digital objects, their behaviour and life cycle. For purposes of the current prototype of *WorkshopAR*, the available digital objects are play models and annotations. Each object has a unique behaviour that will interact with the *Session Manager* or the *Tracking Manager* as needed.

The *Tracking Manager* is the bridge between *WorkshopAR* and the ARFoundation framework. It connects all the components needed to create an AR scene and configures the components that provide AR functionalities like image composition using the feed of the camera and plane detection in the real space. The manager is also associated with the XR Origin object, a component needed in the OpenXR framework to abstract the XR device in which the app is going to be deployed. ARFoundation uses this component to communicate with the functionalities of the mobile device. In summary, the *Tracking Manager* is in charge of:

- Initializing the AR device.
- Managing the behaviour of the main camera.
- Managing the digital objects on the scene.
- Configuring the AR functionalities provided by ARFoundation.

The *Tracking Manager* specifically pulls the functionalities related to plane detection and the creation of visual anchors from the ARFoundation framework. The manager configures these components and keeps track of the game objects used for the visual composition of the scene with the information of the camera. A similar coordination is done with the *Session Manager*, which keeps track of the life cycle of the objects in the network and the data that needs to be coordinated between participants. Figure 4.9 shows a relational model of all the components related to the *Tracking Manager*.

Interaction Pipeline

The connection between the hardware layer of the device and the *digital room* created by *WorkshopAR* follows the architecture proposed by OpenXR. Figure 4.10 shows the interaction flow between components in case of a local interaction with a digital object, like a play model or an annotation.

The local device is in charge of detecting interactions at a hardware level, most commonly inputs in the touch screen, the relative position of the device (accelerometer, gyroscope, etc.) and the image feed of the camera. All the input information is then related to the context of the AR application thanks to the local framework present in the device (ARCore or ARkit i.e.) which relays the raw data of the input to the Unity core engine. In here, the ARFoundation framework uses the Input System provided by Unity to read the raw information of the device and maps it to designated functions implemented by the *Tracking Manager*, which coordinates all the components, either from ARFoundation or from *WorkshopAR*, needed to respond to the input.

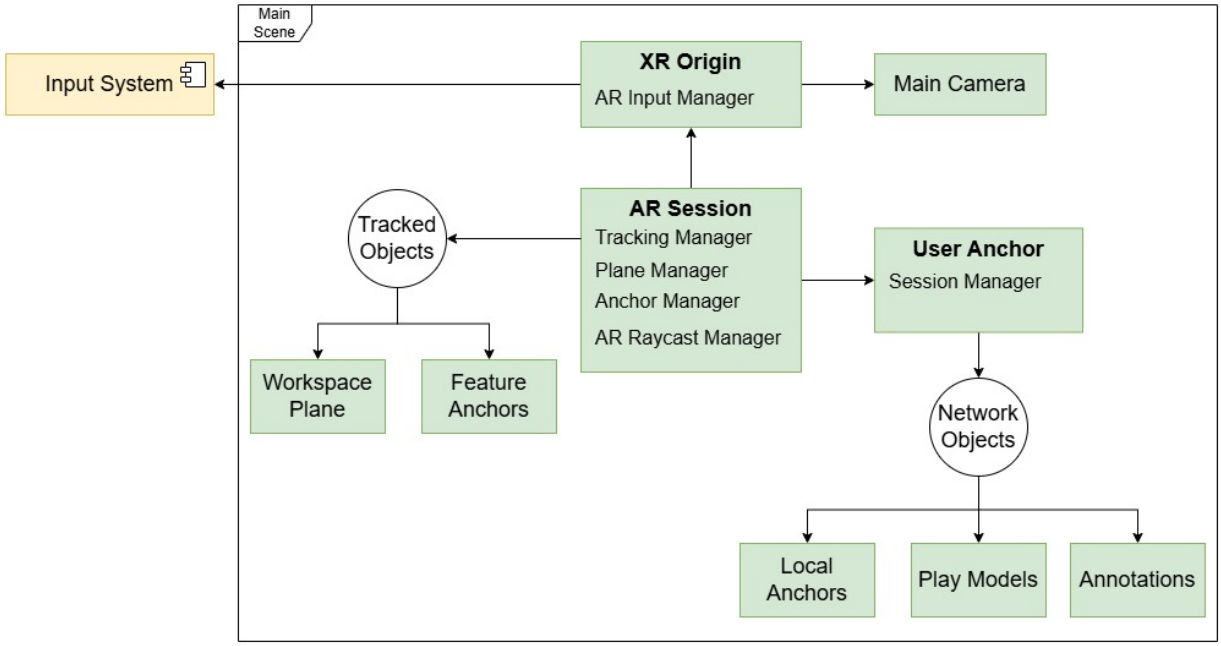


Figure 4.9: Tracking Manager Relational Model

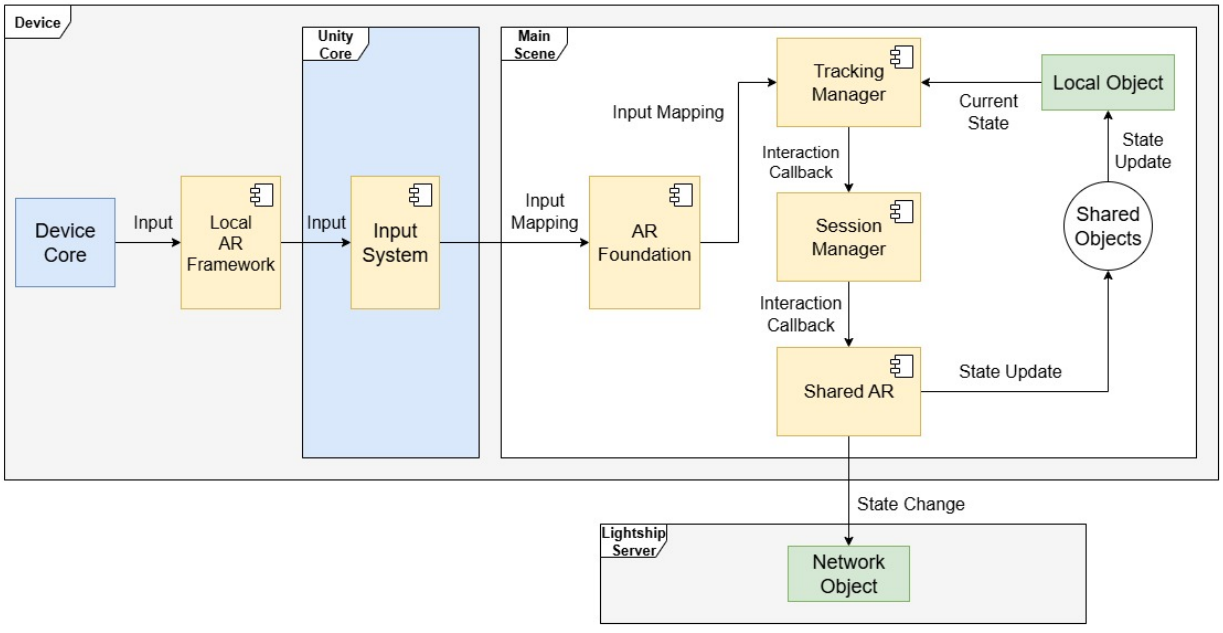


Figure 4.10: Device Interaction Flow

Independent of the components involved in the response, it is first necessary to determine if the interaction changes the state of a shared object. Any change to a shared object is handled by the *Session Manager*, who coordinates the remote network procedures that propagate the relevant information to all the users, and reacts locally when a change is received from other user. The *Session Manager* is in charge of updating the state of all the shared objects, while the *Tracking Manager* only reads the information for visualisation purposes and to manage interactions.

SharedAR supports both server-authoritative and client-authoritative network architectures, as well as the possibility to have dedicated servers or host/client dynamics. *WorkshopAR* follows a host/client architecture with no dedicated server controlling the experience. The users must decide who is going to act as the host. Then, the selected user needs to configure the *digital room* and open it, while the other users connect as clients. If the initial host leaves the *digital room*, it is easy to pass the host authority to any other connected user.

In terms of authority architecture, the host holds server authority for the configuration of the *digital room*, state of the *digital room*, the detected physical plane used as the shared *workspace*, and the physical features detected as visual anchors. Meanwhile, the *User Anchors*, the play models and the annotations are client-authoritative, with ownership given to the user that initially spawned the object in the network.

A final consideration is that, despite being designed as a serverless architecture, *WorkshopAR* needs to follow the architecture enforced by SharedAR, which works as a central server that hosts the shared room and manage the connections of the clients to it. This element is outside the architecture of *WorkshopAR*, and for the end user, they just need to worry about the connection with the host. Figure 4.11 shows a diagram that represents the main components in the network architecture, the objects over which each component holds authority and the most important procedures being transmitted over the network.

In the case that an interaction does not involve digital objects, the pipeline maintains the same architecture. *WorkshopAR* relies on the services provided by ARFoundation for the detection of features using the camera present in the mobile device, as it is shown in Figure 4.4. The specific subsystems used by the prototype are the plane detector, the anchor manager and the AR raycast functionalities.

The plane detector is used to identify flat surfaces in the physical space, one of the steps in the configuration of a *digital room*. Similarly, the position of a digital object can be used to create an anchor in the digital space, which helps improve the quality and stability of the AR visualisation. A new anchor is created in the room every time a new user connects, and these anchors are managed by the host's *Session Manager*. The AR raycaster is needed to interact with digital objects in the AR space or with features in the AR space created by other subsystems. This is a local operation, so it does not need to be propagated in the network. Figure 4.12 shows the interactions of the previously described components in the network architecture of *WorkshopAR*.

4.3.4 Data Architecture

For the implementation of *WorkshopAR*'s prototype, each use session is meant to be a single contained experience with little to no persistence between activities. In terms of the intended use of the application, it makes sense to have continuity of the work done, track progress and

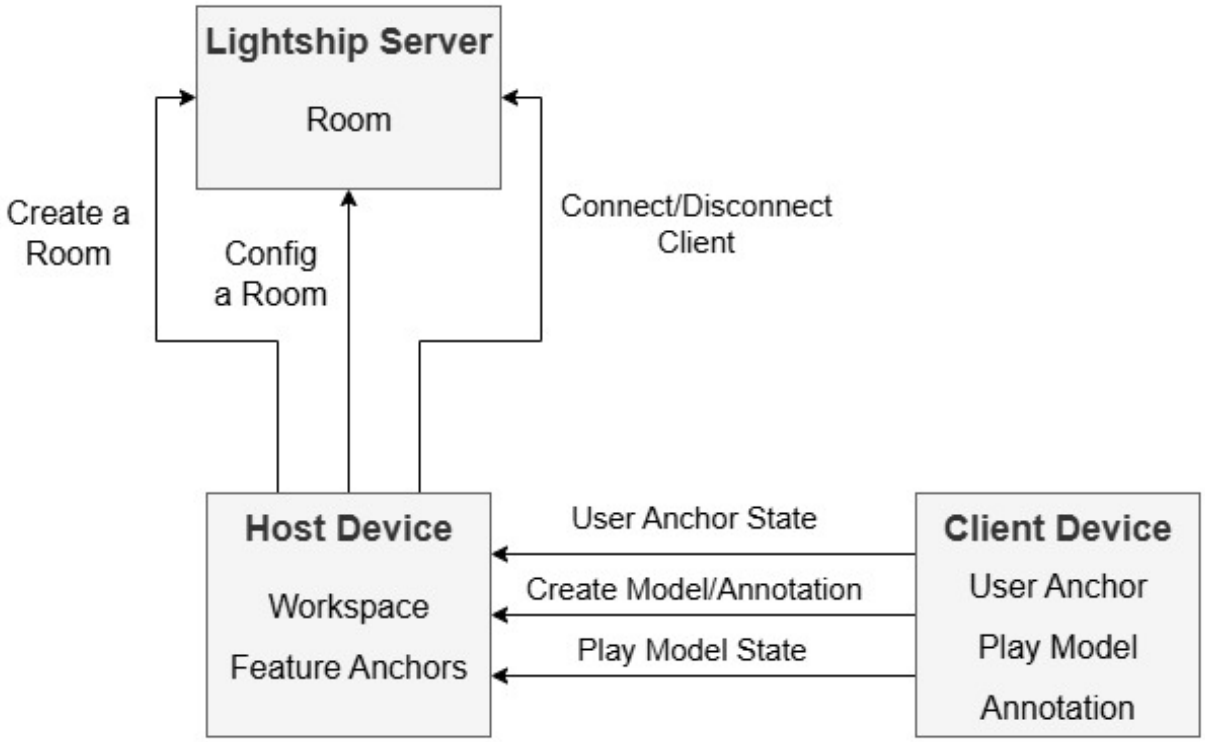


Figure 4.11: Network Authority Architecture

log the activities for future consultation. This is not a trivial design. In the simplest scenario, it would be ideal to keep the state of the *digital room* in every work session performed by the group, keeping track of elements like:

- The users participating in the session.
- Roles and tasks assigned to each participant.
- Goals for the session.
- Digital objects (models and annotations) present in the *digital room* and their current state.

In technical terms, the challenge lies in managing the ownership of digital objects and keeping the layout of the *digital room* even if the original owner is not present in a new session. This can be solved by establishing a protocol to deal with orphaned objects while keeping them in the *digital room*.

There are important architectural considerations in this scenario. First is the responsibility to store the necessary information to rebuild the room in the future. The central server provided by the Lightship service is in charge of hosting the shared room, but does not have the capability of managing all the process necessary for running *WorkshopAR*, including persistence. In this approach it would be necessary to decide where to store the data and who has the responsibility to reconstruct the *digital room* in each session.

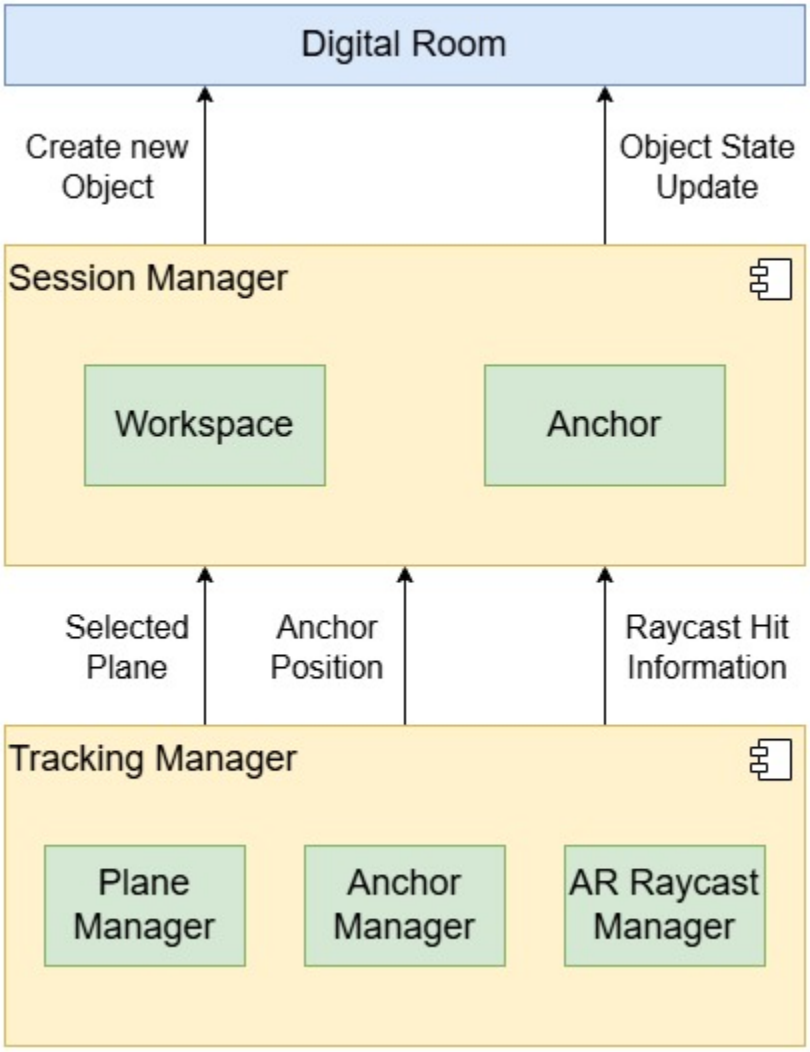


Figure 4.12: Interaction Pipeline with ARFoundation Subsystems

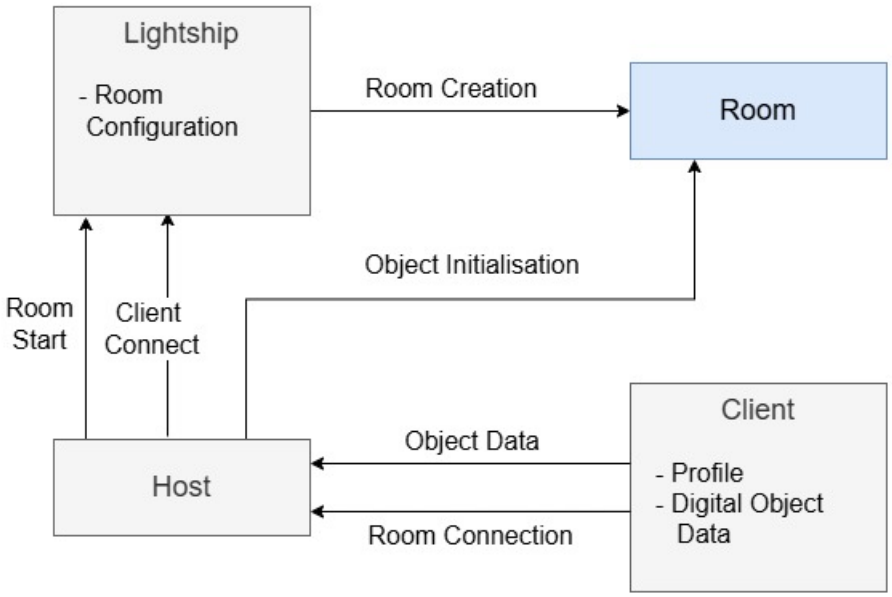


Figure 4.13: Data Persistence and Ownership

If the data is the responsibility of the selected host device, the reconstruction process is simple, but the role of the host users acquires some permanency and there is the possibility of a scenario in which the group cannot continue their work because the assigned host is not present. This puts too much responsibility on a single user.

If each client is responsible for its own data, the architecture is then respected and the host does not have unnecessary responsibility. However, the *digital room* reconstruction becomes more complex and has the risk of not being complete if a participant is missing.

A proper solution would consider the needs of the educational design. In the case of this research project, it is important to give the students the ability to have a flexible group, either because groups are fluid during the classroom's activities, or because different *work sessions* do not necessarily happen with the same participants. The key is to provide the users with the ability to quickly jump into the tool and start working in the session goals, with the application itself and its configuration being as transparent as possible.

In this case, providing the ability to boot up the *digital room* with minimal configuration and previous planning or coordination is the best approach, even at the risk of losing information. Figure 4.13 shows a data flow architecture for this scenario.

An alternative solution is to drop the serverless approach and add a central server. Its main responsibility would be to save and coordinate the data needed to reconstruct a *digital room*. Since the Lightship server is outside the architecture of *WorkshopAR*, it only provides services to control the creation of a room and the connection of clients to it, and a second server would be needed to provide both the persistence of data and the networking services to coordinate the shared interactions.

The role of the educator in the experience can become relevant in this scenario that provides a centralised view of all the activities of a classroom composed of several *digital rooms*. A main server could take the responsibility of storing the state of each room and

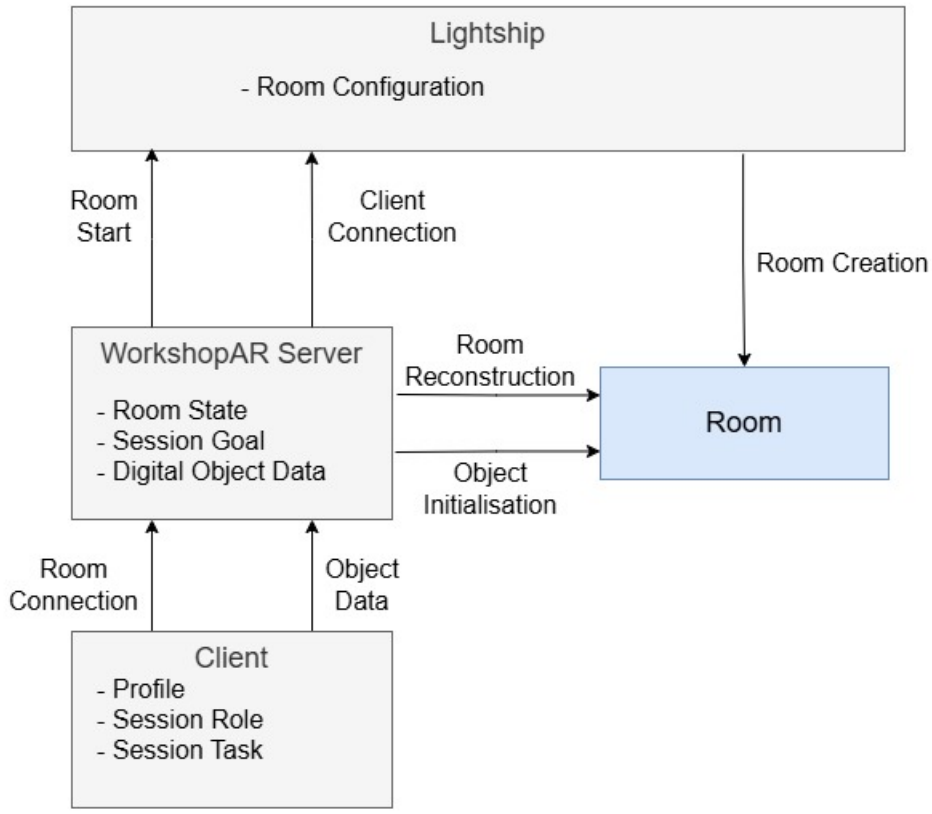


Figure 4.14: Data Persistence and Ownership with a Centralised Server

would coordinate its reconstruction in further sessions without involving the figure of a host or running the risk of losing information. Figure 4.14 shows the same data flow architecture if a central server is included.

For the prototype, no actual persistence of each individual session was implemented, but the general architecture established leaned into the solution proposed in Figure 4.13. The only persistent information of the session was the configuration of the *digital room*, which will be explored in the next section.

Room Configuration

To simplify the development process and to accommodate the group dynamics observed in the execution of the Industry Project course, it was decided that the information of each individual *work session* would not persist over time. In this way the *digital room* creation process would be quicker and the students would not need to organise and sort out information and activities that happened several sessions in the past when the last observation activity took place, a situation that became common due to the data gathering process undertaken and described in section 6.2.2.

In this simplified scenario, the *digital room* is described by its ID, by the image used to determine the shared origin point and by the maximum number of users allowed to connect. This information is required by the SharedAR framework and is managed by the Lightship

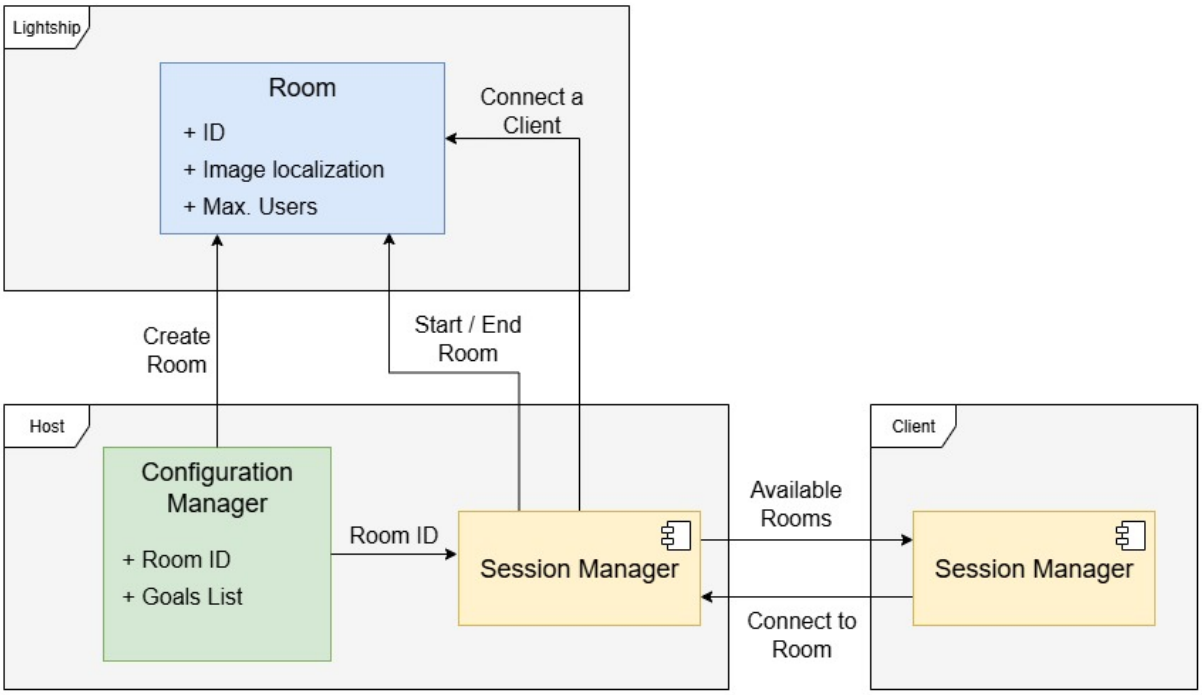


Figure 4.15: Room Configuration Data Flow

server. *WorkshopAR* manages the configuration process and signals the creation of the room, the start of a session, its end, and the eventual deletion of a room.

The user designated as host also needs to provide a list of session goals to share with the group. This information is not mandatory, and it can be provided and changed during the execution of the session itself or completely ignored by the group. This information is stored and managed by the host, and in the end, it would be the current host's decision to use information locally stored to reconstruct a session or start anew. This acts as a middle ground solution between forcing the host to always fill that role in the group and forcing to start the session form zero every time. Figure 4.15 shows a simple data flow of this scenario.

The image colocalization process is a system used by SharedAR based on the image recognition subsystem of ARFoundation. The process requires a base image to be recognised by each client connecting to the *digital room* which will be used as the physical anchor for the shared origin of the room. This means that no positioning information is being stored, instead, the localisation of the origin point is calculated every time a room is booted. The only information stored is the target image in a raw binary data format. This encourages physical and synchronous gatherings, but if information about the room ID and the target image is shared, remote collaboration is also possible, at least in terms of the visualisation of the digital objects being added to the *digital room*, but without much of the local context of the experience. That particular scenario was not tested during the data gathering process.

To create a consistent view of the *digital room* for all participants, the shared origin has to be consistent in terms of position and orientation. SharedAR offers the option to use image recognition or geolocalisation to provide the shared origin initialisation. Geolocalisation is precise to a degree but cumbersome and requires a lot of previous setup. It would also limit

the execution of a group session to the same physical space every time. *WorkshopAR* uses image recognition to simplify the colocalisation process by using a simple image marker that needs to be scanned. This provides flexibility at the cost of a less precise visualisation.

A client device would only need the room ID to initiate the connection and access to the target image to initiate the visualisation. It is possible to type the ID of the *digital room* if the information is externally shared by the users, or it is also possible to ask the system to provide a list of all the available rooms, those associated to the particular application ID of *WorkshopAR*. This configuration allows to easily hop in and out of session between different groups, a behaviour identified in the observation stage of the Industry Project course.

User Profile

The second element that is persistent between sessions is the individual profile of the user. Each user is identified by a nickname and a preferred colour. Both elements are used to create a unique *User Anchor* in the room that is shared and coordinated in the network. This information only acts as an aesthetical choice and does not uniquely identify the user in the session. It is also the only data locally stored in the user's device.

When connected to a *digital room*, each user is identified by a unique ID linked to the current session. The ID is assigned and managed by the host on connection. Once in session, a user can define a current task, also linked to a single session. This is not a mandatory process and is the sole responsibility of each user to manage this information after being discussed by the group. With this setting, *WorkshopAR* emphasises the need to discuss and consider issues related to task allocation, but does not force a particular implementation, and puts the responsibility of discussing the matter in the physical communication process of the group.

Finally, each *User Anchor* offers two visual cues to all other participants: a nameplate with the current nickname and a set of visual markers representing the gaze of the participant, that is, the direction the camera on the user's device is pointing at. These elements represent information about the participant and about the current activities in the *digital room*. Both are also optional, and each participant can turn off or on the visualisation of these elements. Figure 4.16 shows a simple data structure of the user profile.

4.3.5 Use Case Diagrams

The following section will detail the intended flow of the most prominent use case scenarios for *WorkshopAR*, giving emphasis to the components involved and the data transmitted through the network. The main objective is to understand the macro functions of *WorkshopAR* in terms of the components needed to start the development process and quickly identify the most crucial elements that need to be tested. This activity was also a useful tool for the interaction design process and for the initial generation of ideas about how students could be using the software, what collaborative activities should be supported and the behaviours that could be promoted by the experience.

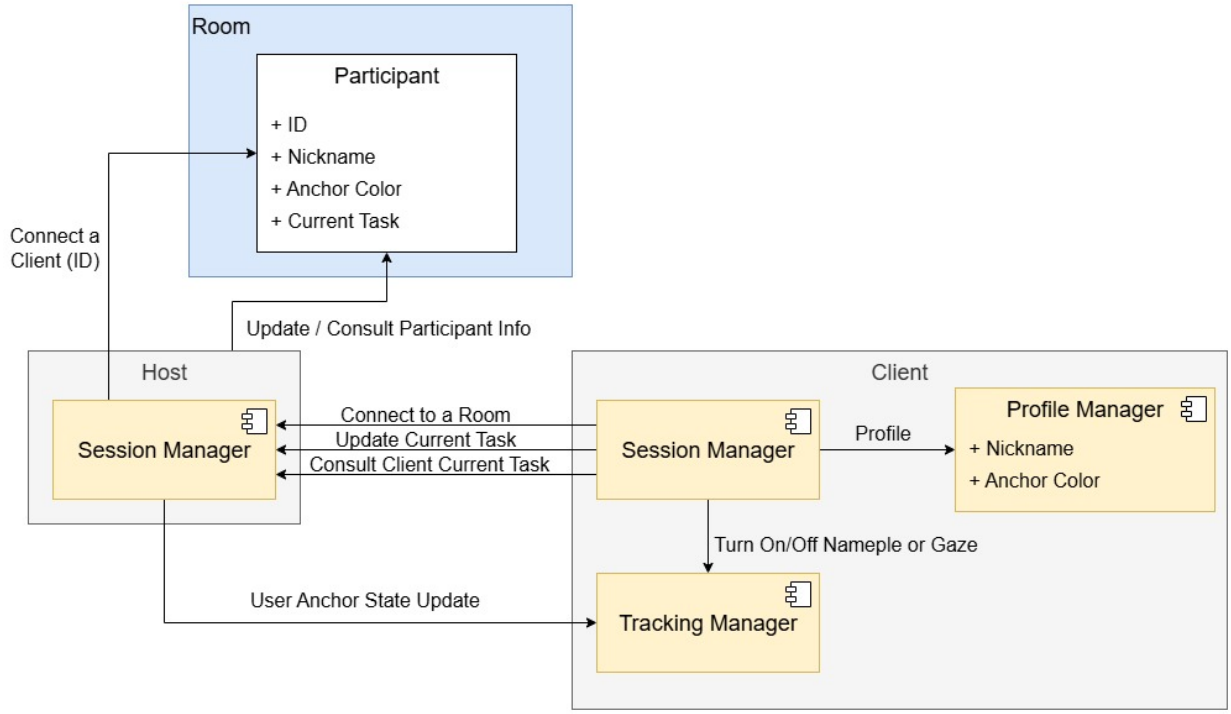


Figure 4.16: User Profile Data Flow

Digital Room Creation and Join

The most basic interaction between users is to create a *digital room* and start a work session. The idea is to distribute responsibilities between what is provided by the tool and what the group must coordinate and discuss physically. Taking this philosophy in consideration, the process of creating a *digital room* can be described in the following steps:

1. Decide the overall objective of the work session.
2. Determine who is going to act as a host and any other roles needed or relevant for the session.

At this point *WorkshopAR* is not involved yet, but its architecture enforces the user to discuss and plan the session in terms of objectives and roles. The first software related step involves the configuration of the *digital room*, meant to be as detached from the host as possible in order to not force unnecessary responsibilities on the role:

3. The host creates a *digital room* by providing an ID, the tracking image and an optional session goal.
4. The host communicates the *digital room* ID to the rest of the group.
5. Each client finds the *digital room* using the correct ID and joins it, becoming a participant in the session.

6. Each client (including the host) scans the tracking image to establish the shared origin, initiating the visualisation of the *digital room*.

7. Each participant specifies a role and a current task if needed or desired.

Each user is responsible for providing the information needed for the session, depending on how much the students have structured their work around *WorkshopAR*. This information can be changed and updated at will. It is also possible for each user to have access to as much information as desired from their teammates, opting for turning on and off visual elements like nameplates and gaze representation, and accessing information about goals and tasks only upon direct interaction.

8. If the current host leaves, the responsibility is transferred to the next client in the list.

9. The session finishes and the room stops when all clients have disconnected.

WorkshopAR provides the opportunity to visualise elements about the organisation and planning of the *work session* but is the responsibility of the users to properly discuss and determine that information and its evolution across the session. Figure 4.17 shows a use case diagram detailing the most important components involved in the process and the data flowing between them.

Thanks to the diagram, it is possible to realise that the bulk of the communication and coordination of information is done through the host and client devices, specifically through the coordination of remote process in the *Session Manager* component. Communication with the Lightship server itself is only done through the host device and is mostly used to initialise the connection of new clients and the initial configuration of the shared origin and all the objects already in the session.

Add and Interact with a Play Model

To give support to the activities in the core of the Industry Project educational goals, it was decided that *WorkshopAR* was best as a tool for communication and planning, helping in the initial steps of the architectural, engineering and management process that are part of the course's activities. The interaction with digital play models is a simple implementation that facilitates ideation and exploration. This resource provides visualisations of the discussions taking place about space, the relationship between different physical entities, positioning of elements and sketching ideas. These interactions are meant to be used when:

- Architectural and construction engineers want to discuss initial ideas of a design in a high level of detail, using the play models as stand-ins for spaces and constructions.

- Construction managers or quantity surveyors need to understand any aspect of the proposed design and need a simple-to-use visual tool to communicate a concept, a question or an idea.

- The group wants to have a shared visualisation or discussion of a custom model that has been imported to *WorkshopAR*.

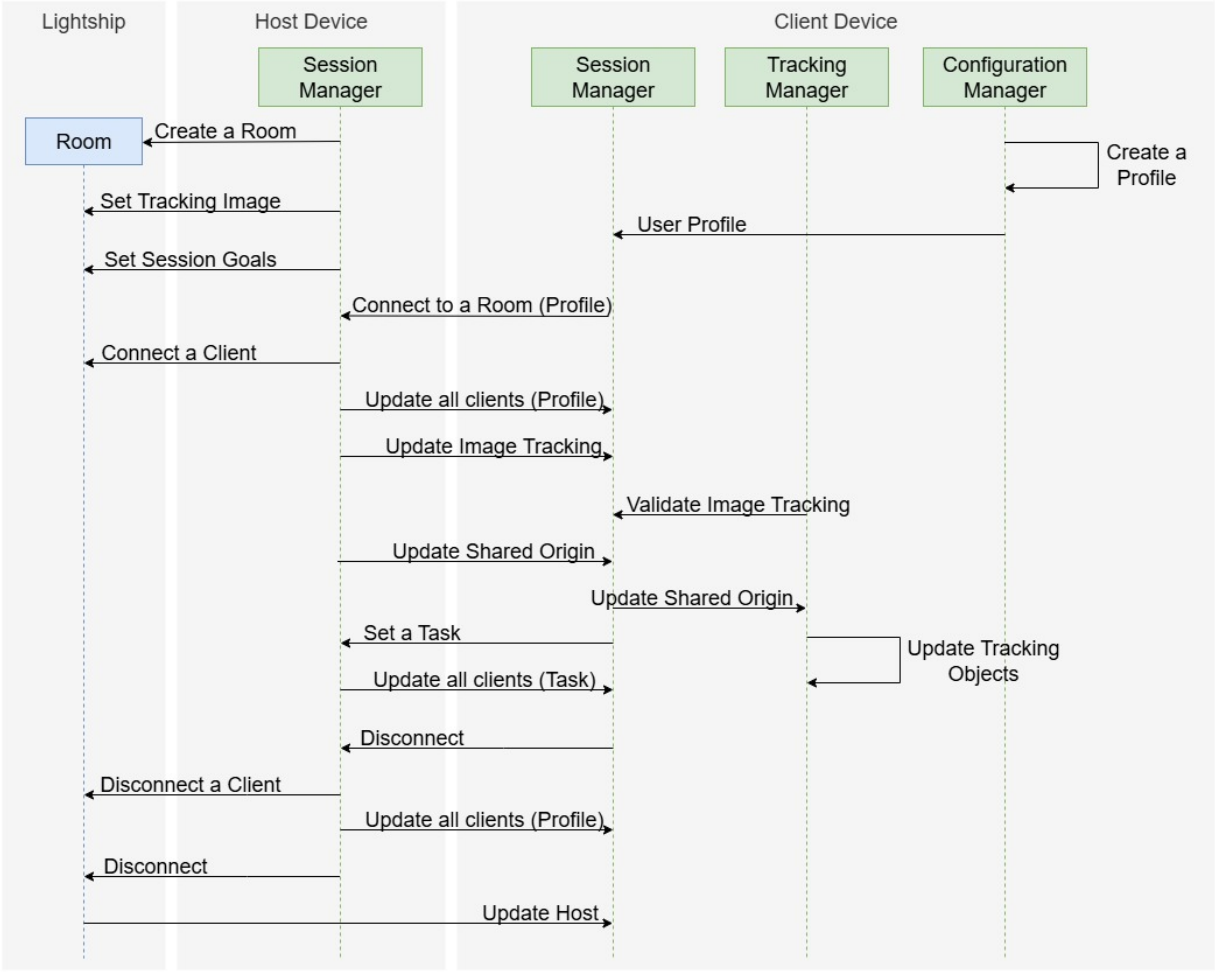


Figure 4.17: Use Case Diagram - Create and Join a Digital Room

The most straightforward version of this scenario involves a participant adding a set of play models to the *digital room* in a particular position and configuration to convey the desired idea, which can then be interacted with by other participants using direct transformations, pointers or annotations. This scenario follows the following process:

1. The participant selects the desired play model from the play models menu.
2. The participant uses the camera pointer to position the model in the shared *workspace*.
3. The participant can tweak the position, orientation and scale of the model. The model is now shared by the group, and its state is being coordinated over the network.

Once the model is shared over the network the matter of ownership and shared interaction becomes important. Determining the ownership of a model is a technical issue and can be boiled down to decide if the host holds the ownership and the authority of the state of every model in the *digital room* or if the responsibility lies with every client, with the host only communicating the changes in state. Considering the size of the groups expected for the data gathering process, the difference between both approaches is negligible.

It was decided that the client should have the ownership over every object spawned and that its state should be client-authoritative, a configuration that would ease the processing load on the host device, but that would require the construction of a protocol to manage the ownership of an object in different scenarios, as discussed previously.

The most important architectural decision related to this scenario is related to the coordination of interactions between a participant and a single model. The interaction needs to consider who is transforming a play model in any given time to avoid conflicts of the state of the object over the network. This requires a proper protocol to request the permission of transforming a model and blocking its use while another participant is actively manipulating it (Wells and Houben (2020) is a good example of a very similar solution). This protocol is implemented via software, needs a visual signal in the UI and can be enforced by a parallel protocol in the physical space implemented by the users themselves. Figure 4.18 shows the use case diagram of this scenario.

Add an Annotation

The concept of an annotation is used to communicate ideas between the participants of a session and have that information linked to the *digital room*. The physical space can act as a whiteboard of concepts, or the position of an annotation could be linked with some element of the physical space to convey meaning.

The general process in this scenario is the same as with the play models, the main difference is in the degree of interaction any user can have with the annotations. As with the play models, any participant can create an annotation using mainly text, although the system can easily be expanded to also use images. The annotation is placed in the room using the Raytracing Manager and the best approximation of the position detected in relation to the shared origin of the *digital room*. This process is important because the position of an annotation cannot be relative to the workspace like with the play models to allow more freedom of where to put the annotation, so it needs to be relative to the space or to a real

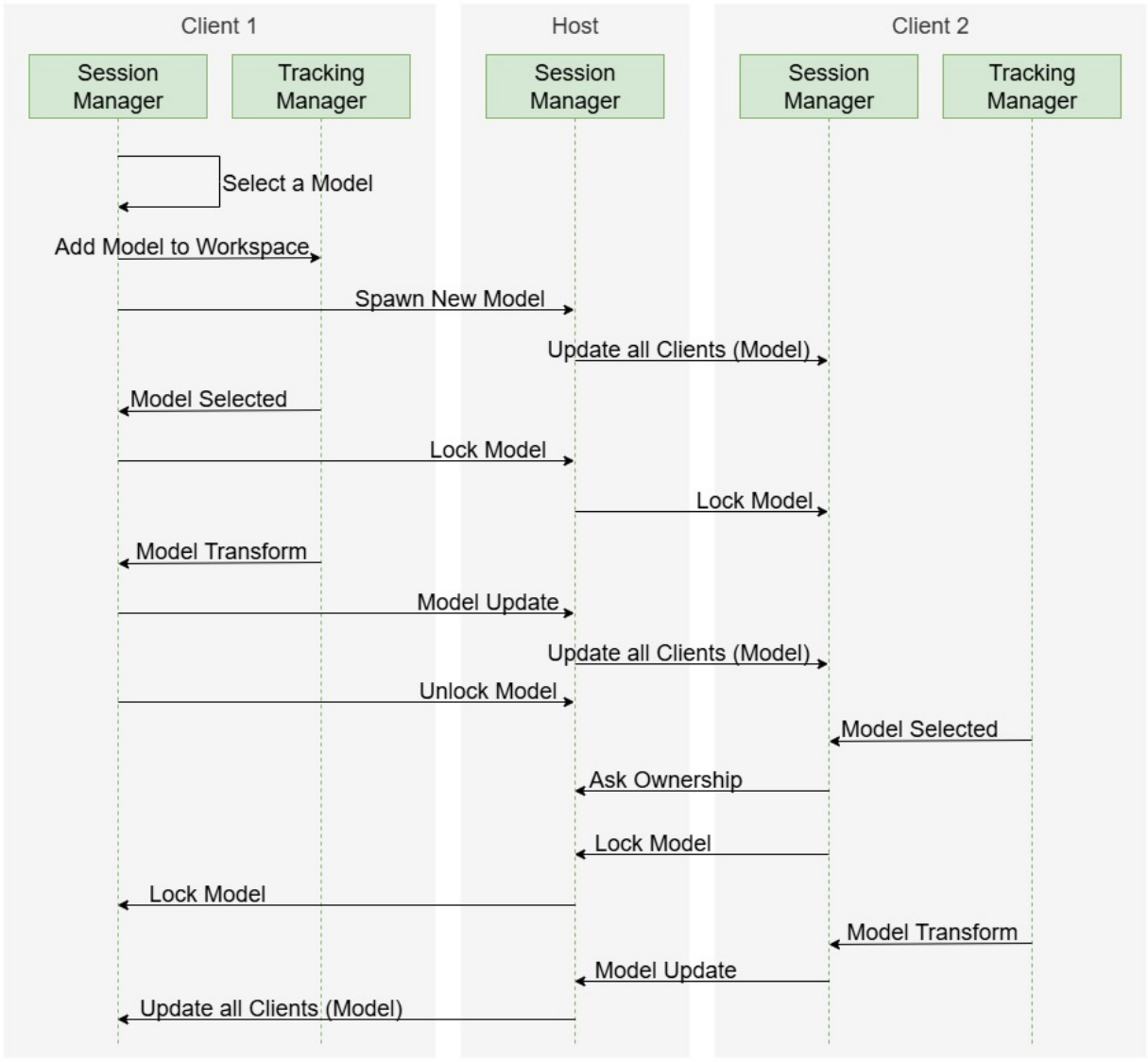


Figure 4.18: Use Case Diagram - Add and Interact with a Play Model

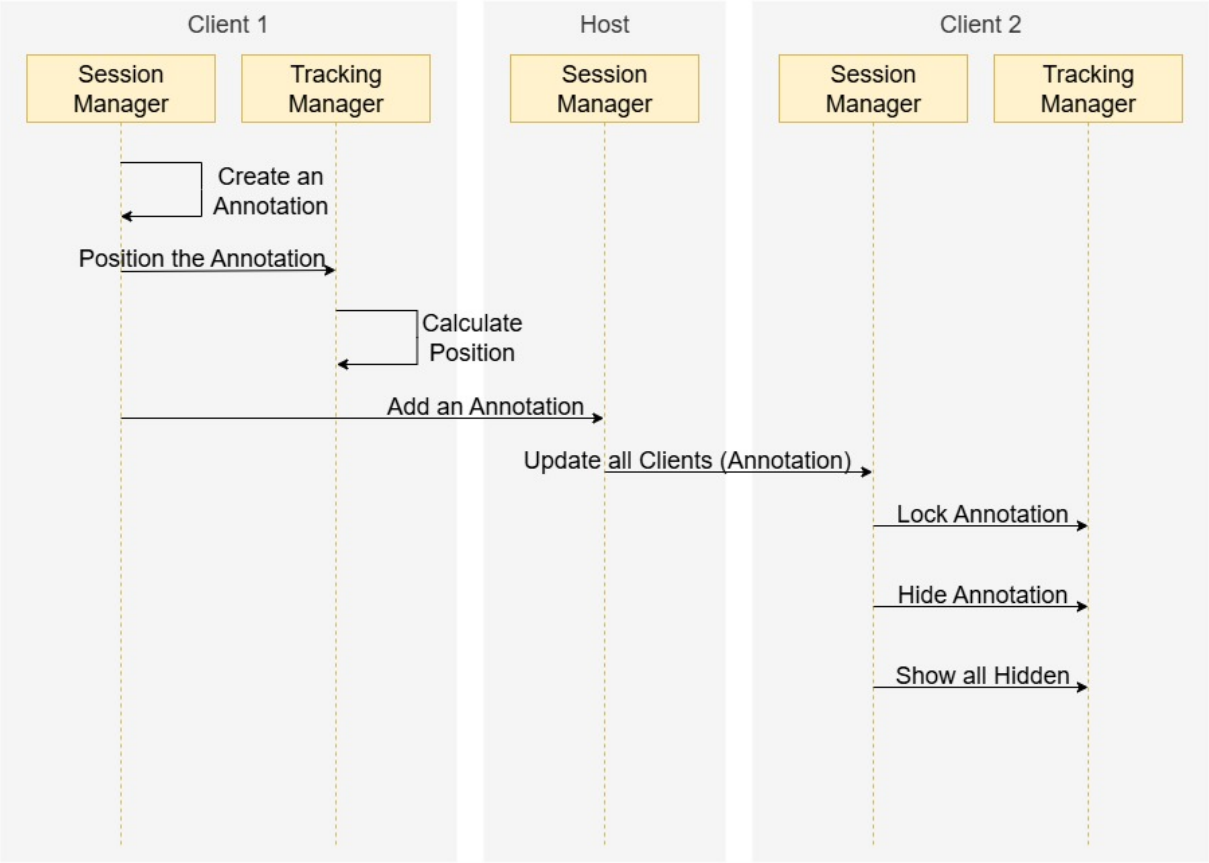


Figure 4.19: Add and Interact with an Annotation

object detected in the room. Figure 4.19 shows the use case diagram for the creation of and interaction with annotations.

It is important to notice that, unlike the play models, each local *Tracking Manager* needs to calculate the position of the annotation before transmitting it to the host, which creates discrepancies when updating the information in each client. Additionally, all interactions with the annotation are local because they only concern with each participant's visualisation of them.

Propose and Participate in a Debate

The final big interaction with *WorkshopAR* is to support a debate or vote in the group, to mediate the discussion and to visualise the data being used in the conversation. The role of the software itself is minimal, letting the participants handle the flow of the process themselves. The application limits itself to show a visual indication of the objective of the discussion, the current state of the process and the responses proposed by the participants. *WorkshopAR* uses simple and quick to read emotes for this purpose and proposes this three-step process for the whole activity:

1. One of the participants creates the debate by providing a question and possible options.

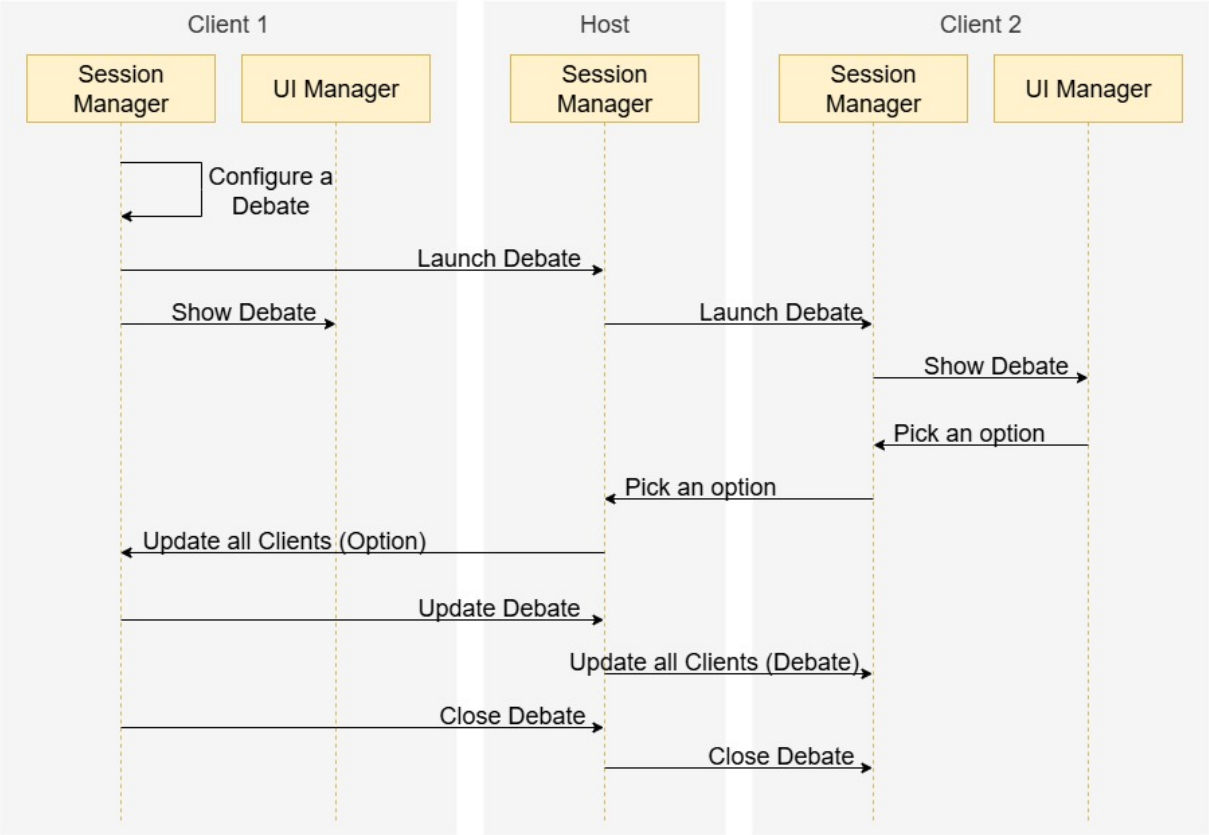


Figure 4.20: Propose and Participate in a Debate

All participants receive the debate prompt and have access to the questions and the possible answers.

2. Each participant can select an option, and the selection is shown to all other participants.

3. When every participant has answered the prompt, there is an opportunity to discuss the answers and change emotes if desired. This process is coordinated by the participants and not the application.

At this point the participants can opt to continue with the debate or conversation outside the control of *WorkshopAR*, referencing the information displayed by the app if they wish so. On the other hand, the group can structure the activity around the software and keep editing the debate or creating new ones to keep the conversation flowing. Either approach is valid and an interesting analysis point in the future.

The decision to create the emote system, or at least a simple prototype of it, derives from the feedback gathered from the users. They proposed the idea as a more interesting and involved way of handling the responses of the debate, as well as a tool that could be used outside this one scenario. In the end, the whole debate process is simple and hints the users at a structure they can use but without forcing them into it, which is the main philosophy for the entire design of *WorkshopAR*. Figure 4.20 shows the use case diagram for this scenario.

4.4 Final Thoughts

The exercise in architectural design described through this chapter had the main objective of establishing the guiding principles behind the development of *WorkshopAR* and the way they aligned with the goals established for the research and the educational design, as well as informing the decisions taken to facilitate development and reach a satisfactory set of conclusions for the research.

From the architectural design process, it was possible to identify key elements of analysis related to the research questions, specifically SQ5 and SQ6, those related to identify the elements in the technological intervention that influence the most in the learning design. All the different use scenarios and the technologies implemented to solve them required to be aligned to the activities done in the Industry Project course. The analysis focused on understanding as soon as possible how *WorkshopAR* could be integrated to the expected workflow of the classroom and what possible effects could be foreseen in the behaviours of the students.

One of the most relevant examples presented itself during the analysis of the debate/voting use case. Initially, the proposed approach considered information found in the literature about collaborative work by establishing a process that the users could lean into if the communication in the group was poor or lacking purpose (Galbraith and Webb (2013) and Gardner and Korth (1998) for example). The process that the users had to follow was initially in the likeness of:

1. Launch the debate activity
2. Wait for the participants to confirm
3. Show an AR representation of the debate
4. Prompt for an introductory question
5. Wait for votes
6. Show an AR representation of the results
7. Prompt for discussion
8. Close debate activity

This process was also initially adapted to different types of debates, like those based around yes/no questions, multiple options or open discussions. At one point it was also important to distinguish between a vote using the UI or using models in the AR space. It is possible to see remnants of this approach in the task design of the gestures analysis described in section 5.1, as well in the general structure of the process shown in this chapter, but overall, the approach to implementation changed substantially.

The main source of change came from the data obtained during the architectural analysis paired with the previously mentioned research. The result was a simpler process more focused on flexibility and options rather than on structure. In that way, the final users could adapt the tool into the more unstructured flow of the classroom.

Other instances of redesign and adjustments to the original ideas behind *WorkshopAR* were a direct result of investing time into the architectural design, and of testing and revising such design. Early interactions with users and revisiting the architectural plan during the iterative implementation of the software were key activities to obtain these results, as can be seen on section 6.3.1. Some other aspects of the functionality of *WorkshopAR* that were refined by comparing the architectural proposal with the needs of the learning design were:

- The responsibilities of the student taking the role of host, which ended acting as the leader of the session or the group. This clashed with the more open structure of the course and the way the students were required to work.
- The structure imposed on the ownership of objects, which, in contrast to the previous point, was given more structure to facilitate development and give more clarity to the use of the application.
- The lack of persistence of data, that, in a different tangent from the previous points, prompted the students to improvise on tools and processes to keep track of the information between sessions.

Overall, the architectural design process was flexible and was evaluated in each iteration. Akin to the role that software architecture takes in more agile-focused developments, the architecture of *WorkshopAR* focused more on creating a birds-eye-view plan for production, aligning that plan with the objectives of the development and documenting the process with just the necessary elements to facilitate communication and evaluation (Babar, 2009). An effort was made to create enough documentation to reflect the development process of *WorkshopAR* without overfocussing on formality or on an exhaustive coverage of all the details of the final product.

The aim of this chapter was to provided enough insight in the development process followed for *WorkshopAR*, on the reasoning followed for the decisions taken in matters of technology and the plan proposed to tackle the implementation stage. The architectural design also reflects the changes and adjustments that took place thanks to the data obtained from testing. Finally, it is possible to draw some preliminary conclusions about the technical aspect of the overall research:

First, as with any exercise within the TEL context, the learning design process and the execution itself of that plan, will be heavily influenced by elements of the technical development. It is very difficult to create a generic, one-size-fits-all technology that covers every problem in a learning scenario. The available literature shows the pitfalls of overpromising the benefits of any technology (F. Wang & Reeves, 2003), and the most successful approaches are those that align the learning context and the technology used before any development starts (Barr, 1990).

Second, for this project, in which AR was the core technology involved, it was important to follow a rigorous design process for the interactions proposed that considers what the market is converging to and the expectations that the users are starting to develop. AR technology is entering little by little into commercial maturity, creating a set of design tropes and a common language that must be considered, studied, and obviously, worked upon and challenged (Liu et al., 2022).

Third, the design stage helps to idenify how the users will likely approach the usage of a tool. If the design process is paired with early testing and a substantial analysis of the involved users and stakeholders, it is easier to gather data and start drawing conclusions as soon as possible. It is important to consider how a technology is achieving a particular objective, if at all, and how it is integrated into the bigger context of the classroom, the activities that is supposed to support and all the other goals, behaviours and tangential learning that is promoting. Teaching technology deals with a very complex context that is both, easy to misunderstand and underestimate. As shown in this chapter, it is possible to go over a good deal of these hurdles by following the proper process and creating the right mindset in the development team.

Chapter 5

WorkshopAR - Implementation Process

This chapter will continue the technical analysis of *WorkshopAR* by exploring the implementation process. This analysis will highlight the research done to identify and propose a suitable interaction design for the context around the project, the evolving tendencies in the implementation of Augmented Reality (AR) experiences and all the information regarding good and bad practices that had been found in the literature.

It will also offer a comparison between the plans and ideas proposed in the architectural design against the actual implementation of the software, identifying the reasoning behind such changes and how the context and circumstances of the development shaped the final product.

Chapter 3 detailed the reasoning behind the chosen development methodology, explaining how an iterative approach allowed for experimentation and flexibility, and that it better accommodated the constraints in time and resources found in the research, facilitating a *just-enough* approach to architecture, design and implementation. As a result, *WorkshopAR* undertook a development process in two iteration cycles which ended up with the testing and deployment of a prototype used for observation and data gathering. Both cycles were structured around a design phase, an implementation phase and quick adjustments. In between iterations it was possible to allocate some time for data analysis and planification for the next cycle.

Iteration 1 focused on building and testing the functional AR technology behind *WorkshopAR*: the shared AR space and the fundamental AR interactions. The overall goal was to explore the main use cycle of creating a *digital room*, starting a session with other users and sharing visualisations of different digital objects. The in between testing and analysis was used to better align WorkshopAR to the particularities of the Industry Project course, as well as incorporating key observations provided by initial test users.

Iteration 2 focused on providing the needed functionalities to fulfil the use cases identified in the architectural design process, those that provided most value to the users and the research. A final analysis of the results was done to identify possible solutions to the issues and ideas generated from the data gathering, both at an implementation and design level. There is also a discussion of possible future steps for *WorkshopAR*, of how the software can evolve and the lessons learned for future or related scenarios.

It is also important to mention that this implementation process ran in parallel to the development of the case study, specially to the observation sessions. To use as best as

possible the available time for development, several of the functionalities of *WorkshopAR* were identified and tested as needed during the development of the course, and the software itself evolved throughout the execution of the case study. The description of the implementation process will be separated from the analysis of the case study to keep this document as clear and accessible as possible, and to not repeat to many times the same observations and discussions. A special effort will be done to show the overall evolution of *WorkshopAR* as a software and to highlight the major changes to development influenced by the interactions with the users and the circumstances observed in the classroom.

The following sections will describe this implementation process and provide a post-mortem of the activity to promote discussion and analysis of the results. Section 5.1 will first detail the research done as part of the interaction design of *WorkshopAR*, research that informed the approach that the software was going to take in relation to AR technologies and how to implement a set of interactions for the collaborative and multi-platform tasks present in the context of the development. Section 5.2 will describe and show the results of the development process, organising the analysis around the two iteration cycles described previously. Section 5.3 will act as a final analysis and conclusion of the results of the implementation process, the development of *WorkshopAR* and for the technical section of the research in general.

5.1 Interaction Design

An important effort in the construction of *WorkshopAR* was dedicated to the design of the interactive elements at the core of the experience. The interactions that received the most attention during the design process can be classified in three:

- Interactions with digital objects (user anchors, play models, annotations) in the AR spaced created for the room.
- Social interactions between participants in relation to group management and the activities of the course.
- The controls of the tool itself, the individual components and the flow of the work session.

These interactions were prioritised because they represent the tools that *WorkshopAR* uses to promote the behaviours and ideas around collaboration at the core of the objectives of the project. It is also important to take into consideration that this process was executed when there was already a clear idea of the learning objectives needed for ENBU79X/89X, but prior to any activity or observation session.

The interaction design was proposed to be as invisible as possible, without interfering too much in a negative way or hindering the academic work of the students using the tool. In a similar light, the project also offers the opportunity to explore solutions to a variety of interaction problems associated with the use of AR in mobile devices such as:

- Simultaneous interaction with digital objects that are shared with other users.
- Organise and select information.

- Use and understand social cues from other users.
- Plan and organise tasks for a common objective.
- Jump from using the AR application to any other external activity and vice versa.

The following section will explore all these aspects of the interaction design in two parts. The first part will focus on general AR design and will detail the research done to understand how to use mobile AR devices in social and collaborative activities, and the user-guided design followed to identify the best approach to the overall AR interactions needed for the implementation of *WorkshopAR*.

The second part of the section will detail the decisions taken for the top-down interactions implemented for *WorkshopAR*, that is, the final implementation and user experience for activities related to create a *work session*, interact with the digital objects in the *digital room* and structure the collaborative activities of the group using *WorkshopAR*.

5.1.1 Collaborative interactions in AR

There is a a need to consider any development within the broad spectrum of mixed realities as a product intended for the general consumer. This is why the development of *WorkshopAR*, although envisioned as a research prototype, aims for an implementation guided by a user-centred, human-centred design approach.

For a human-centred approach it is important to consider the requirements that are directly related to interactions of the end user with the core utility of the product and the context in which they happen (Boy, 2017). This general design goal is highly relevant for *WorkshopAR* if seen as a product introducing AR technology to the collaborative education context. AR technology remains relatively new to most consumers and most of them have little or no contact with it in their daily routines (Chang et al., 2023). Consequently, users have not yet developed a consistent digital literacy around these and similar technologies. Is equally uncommon, even for experienced users, to have any form of expectations about the behaviour and allowed interactions of any development. Even when an application is deployed in a more recognisable platform, like a smartphone, the affordances and interaction methods that the users are accustomed to may not be the same or may be entirely absent.

Several efforts have been made to create a shared language for developers to use in the interaction design of their applications, and to solve common problems with consistent approaches. Research studies such as those conducted by Piumsomboon et al. (2013) and Wobbrock et al. (2009) have formulated and compiled an array of intuitive gestures tailored to various forms of AR and Mixed Reality (MR) interactions. These proposed sets of gestures encompass a broad spectrum of general interactions, ranging from object selection and manipulation to complex tasks like file browsing and content editing. However, these studies worked under the assumption of single-user interactions.

While some interactions may be the same in both scenarios, others are unique to multi-user settings. Moreover, it is important to note that collaboration is not a given characteristic of multi-user scenarios. The objective of the research described in this section is to explore the particularities of collaborative interaction in AR. Using the same user-centred methodology proposed in the studies cited previously, the aim is to identify common tasks executed in a

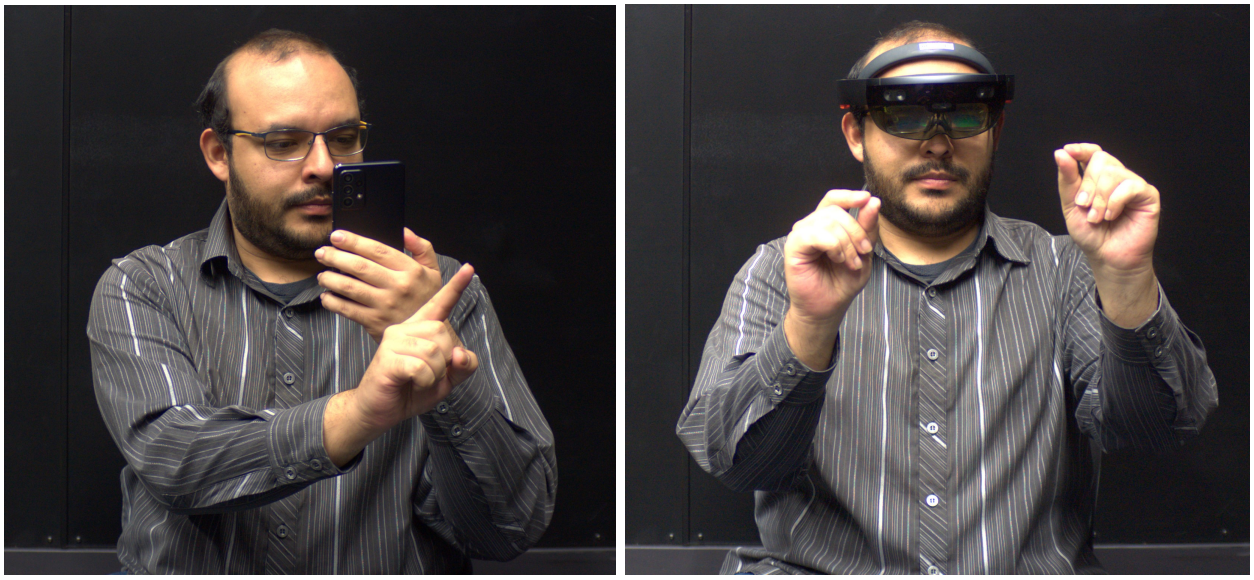


Figure 5.1: Setups for Scenario 1 (using a smartphone, left) and Scenario 2 (using a HoloLens, right)

collaborative setting using different forms of AR technology. Based on that, the result is a proposed set of gestures that capture the most natural interactions that users perform and tend to converge to. The results were directly used as a design guideline for the interaction design of *WorkshopAR*, highlighting effective strategies to tackle tasks related to the use of AR in the collaborative scenario and the use of mobile devices as the focus for deployment.

Research Methodology

The interaction design process was guided by a three-step procedure:

1. Identification and selection of tasks.
2. Data collection from participants proposing interactions for the identified tasks.
3. Analysis of the collected data to identify convergent approaches, recurrent issues, and common behaviours.

In total, 24 different participants were interviewed with a median age of 41 and standard deviation of 11. Of the participants, 66% were women while 34% were men. In terms of demographics, 20% of the participants were university students with careers mostly in design and computer science. The remaining participants were professionals in different fields like IT, medicine, and administration.

Two different scenarios were designed for the test. In Scenario 1, participants were equipped with a smartphone in one hand, leaving the other hand one free to interact during each task. Scenario 2 involved the use of a Microsoft HoloLens headset, which afforded the participants the freedom to use both hands. Figure 5.1 shows examples of each scenario.

Both scenarios facilitated distinct modes of interaction, which were anticipated to influence the participants' thought processes and instinctive responses for each task. It was hypothesised that:

- Scenario 1 would prompt individuals to interact with the screen rather than the free hand.
- Scenario 2 would prompt more air gestures.
- Each scenario would converge to its own set of gestures rather than both converging to the same general set.

It is also important to note that at this point in the design of the software, it was not clear if *WorkshopAR* was going to be implemented with full cross-platform compatibility in mind, and it was therefore important to identify how users proposed gestures for the same task in different scenarios. If they diverged enough, it would be necessary to create two different input systems. If there was some form of convergent set, that method could be used or expanded upon for the interaction proposal.

As noted in previous sections, Piumsomboon et al. (2013) proposed a set of common tasks to perform in an AR application. These tasks were classified into the selection, manipulation, and transformation of digital objects. Nowadays these actions have become common and expected in any environment that requires 3D interactions, with the particularity that these tasks are all related to single-user experiences. Based on ideas present in previous works (Pinelle et al., 2003; Scoular et al., 2020), 14 tasks were identified, representing the most common activities done in a collaborative activity and that could be supported by an AR application. Three principles guided the final selection:

- All or most members of the team are present in the same place. Remote collaboration was considered but not enforced or assumed.
- All members of the team have access to the same AR application but not necessarily to the same platform nor do they have the same means of interaction.
- The context in which the collaboration is done can be varied (education, work, problem solving, etc.) with the objective of being applicable to any form of collaborative activity.

Table 5.1 shows the list of selected tasks divided into three distinct categories. The first category refers to asking another participant to pay attention to an element that is part of the experience, often relating to its position or some describing characteristic. This action has been generalised as pointing and has also been separated into three similar tasks with the purpose of analysing whereas the type of element being pointed at would change the behaviour of the participants. These tasks would ask to point at a digital construct created by the app, at a physical or real object in the real space used for the augmented experience and at another person participating in the experience with them, another human user.

The second category refers to the actions the team could be doing simultaneously while interacting with the digital constructs provided by the application. Most tasks identified for this category overlapped with common activities proposed in previous works, such as selecting,

Table 5.1: Proposed Collaboration Tasks in AR

Category		Task
Pointing	1	Pointing at a digital object
	2	Pointing at a physical object or space
	3	Pointing at a person
Shared Manipulation	4	Hold an object
	5	Share an object with someone else
	6	Take an object into a private space
	7	Undo an action
	8	Take an object out of the private space
Team Management	9	Vote for an option in a menu
	10	Vote for an option in a collection of digital objects
	11	Ask for the attention of others
	12	Pause current participation
	13	Give someone the turn to speak
	14	Ask for the attention of all the teams

moving, and transforming objects. The collaborative context of this study would not change substantially the way participants would approach any of those actions. To gather more pertinent data, only tasks related to sharing objects between team members were selected.

There is also a proposed distinction between a shared and a private space in which each member of the team can interact with different digital constructs, a concept similar to the ideas discussed in works such as Lebeck et al. (2018) and Reilly et al. (2014). The primary objective of this addition was to identify how the participants would visualise and interact with these spaces and to investigate whether the different scenarios would influence their ideas and responses.

The final category are elements common to team management (Zigurs & Munkvold, 2006), those that could benefit from AR augmentation, or at the very least, be compatible within an AR setting. This assumption was particularly relevant given the decision to maintain synchronous team interactions within the same physical space. This category also considers actions done by an individual managing an activity for several groups at the same time, like a teacher or a coach guiding the experience.

All the selected actions reflected scenarios that could be present during the observation sessions in the case study but did not necessarily reflect the actions and functionalities tested during the final observations and the real usage of the tool.

A simple application was built to visualise animations representing each task. This also allowed a more realistic sense of how the activities would be carried out using the assigned device. The participants were able to only see the animations but not interact with the digital constructs in any way. They could also repeat the animation any number of times and move between the animations of different tasks at will. The application worked in the exact same way in both scenarios. Figure 5.2 shows some examples of what the participants could see in the application.

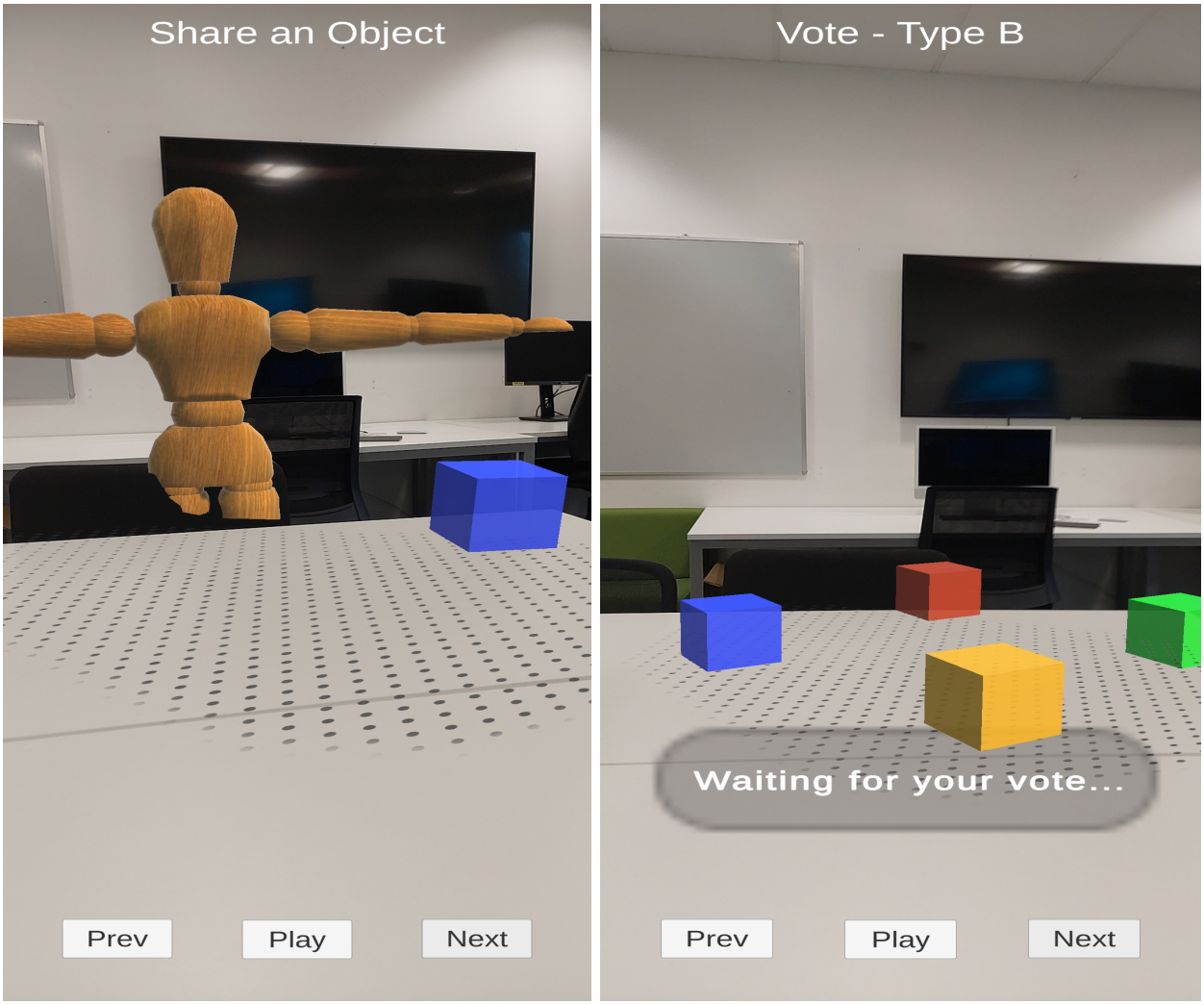


Figure 5.2: Example Views of the Share an Object (left) and Vote with Objects (right) Tasks

Each participant was assigned one of the two scenarios (smartphone or HoloLens), alternating between the options to ensure a balanced distribution. Each participant was given a brief introduction and an explanation of what was expected of them by the researcher. Additionally, they were given a brief tutorial of the basic usage of each setup. Special emphasis was placed on showing how they could put their hands in front of the camera to simulate an interaction, but they were still reminded that they could do whatever they thought would be most natural or straightforward to achieve the action presented to them.

All participants would then proceed through each task performing any number of interactions that would come to mind and trying to verbalise their thought processes and logic. Participants could propose any number of interactions. If none of the proposed interactions were air gestures, the researcher would remind them of that possibility. Tasks were always given to the participants in the same order to simplify the process of explaining the task context and managing the flow of the session.

The specific emphasis on air gestures is due to their strong association with AR technology, which often uses image recognition techniques to track the users' hands and use them for interactions in a more natural and intuitive way (Gavgiotaki et al., 2023; Y. Lu et al., 2022). It was also theorised that participants would not necessarily be familiar with either the technology or those common interaction metaphors, so it was decided that an explicit mention of air gestures after the first round of proposals made by the users would help in the generation of ideas and would also help gather data concerning the hypotheses built for each scenario.

To capture the raw data, all sessions were recorded with a video camera for analysis. The recordings took place over several weeks and in different spaces, sometimes with the participants seated and some other times standing, but always with the same equipment, the same test software, and following the same procedure.

Another important decision was to gather the data of each participant individually. Although the interactions were associated with group activities, there was no need, nor did the process gain anything by simulating the full teamwork experience. On the other hand, if the process would have been more complex, it would have been necessary to coordinate several participants in time and space, and the mock-up software would have also grown in complexity to accommodate several users. It was deemed as an unnecessary development. The procedure clearly explained to the participants that the activity meant to simulate a teamwork scenario with other humans, and some measures were taken to add to the animations presented by the software simple representations of other users to give the participants a visual idea of the scenario presented to them (See Figure 5.2, left).

Each of the recordings underwent analysis to create a transcript of all the participants' comments and ideas, as well as to identify common thoughts, problems, and solutions. Video footage of each session was processed to compile a library of all the gestures performed for each task. Each individual performance of a gesture was given a score from 1 to 3, with the highest score given to the first gesture proposed by a participant. If a participant proposed two or more gestures or proposed a gesture after being prompted by the researcher, those gestures were given a lower score. This meant that gestures with a higher score were performed the most and could be interpreted as the most natural or intuitive reaction for most of the participants. All gestures after the third proposal received a score of 1.

A total of 478 gestures were proposed for all tasks. Although each task clearly converged

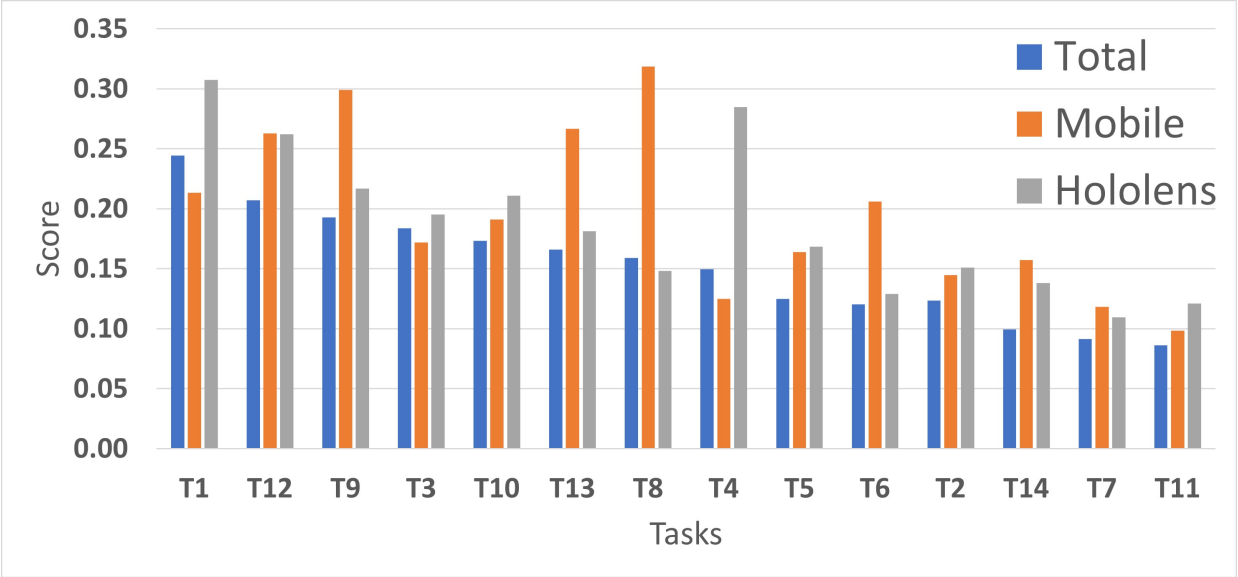


Figure 5.3: Total Agreement Scores for Each Task, Separated by Scenario

to a specific set of gestures, agreement in general was low. For each task, agreement was calculated using equation 5.1 (Wobbrock et al., 2005).

$$A = \sum_{N} \left(\frac{P_s}{P_t}\right)^2 \tag{5.1}$$

In this equation, Pt is the total number of gestures performed for a task, and Ps is the number of times a distinct gesture was performed by different participants. This gives a value of agreement for each task up to 1, which would mean that every participant proposed the same gesture for the task, while a value closer to 0 means that every participant proposed a different gesture. Figure 5.3 shows the level of agreement reached for each task and in each scenario in descending order.

Overall, tasks 1, 12 and 9 had the highest agreement, corresponding to pointing at an object, pausing your participation, and voting for an option on a menu. Although these tasks are the most prominent examples, all of them behaved in the same manner, with most of the participants agreeing on one or two gestures, but the rest proposing a very granular or unique set, generally bringing down the agreement score significantly for all tasks. It is also important to note that the agreement score for both scenarios aggregated is a bit lower than when separated by scenario. Tasks 8, 9 and 13 had a better score in the mobile scenario, mainly because they were strongly associated with touch actions on the screen and most participants converged to such interactions. On the other hand, the HoloLens scenario had better scores for tasks 1 and 4 (point to and hold and object), probably because the tasks suggested obvious or natural hand movements to which most of the participants converged.

Proposed Interaction Gestures

Based on all the data provided by the participants, a library of 39 gestures was selected as the final user-driven selection. These gestures cover 56% of the total proposals and the set of

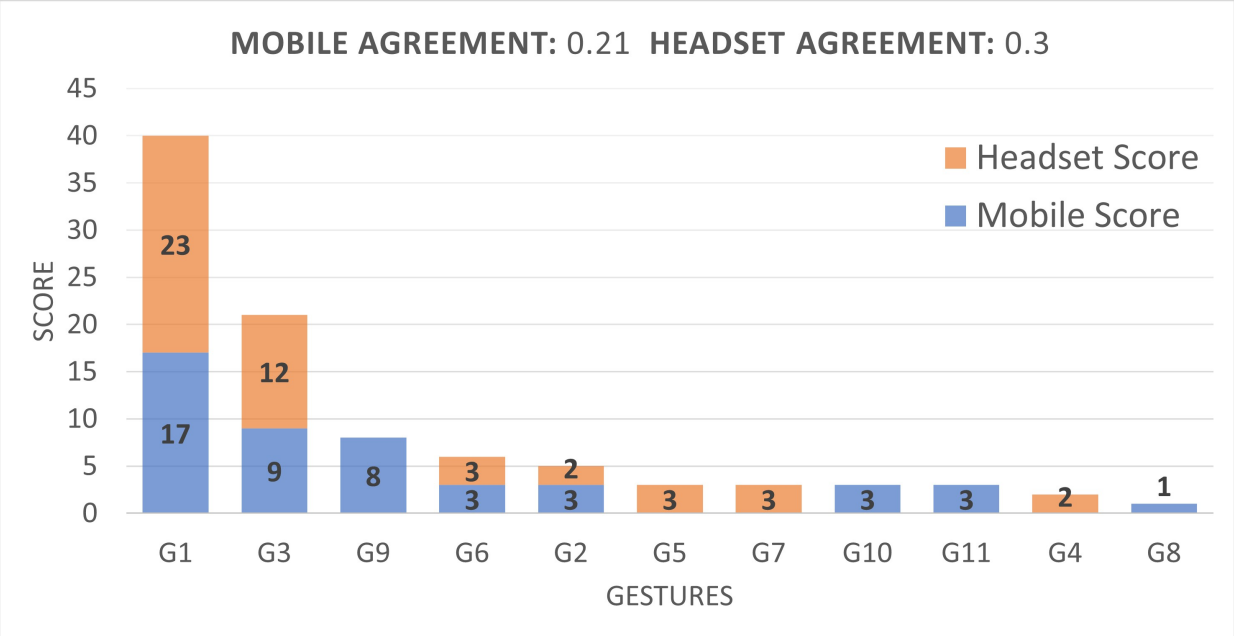


Figure 5.4: Agreement scores for unique gestures in Task 1

each task represents between 50% and 70% of them. The following section will show the final agreement score for all the unique gestures identified in each task, as well a visual example of the gestures selected for the final collection, the one that exemplifies best the ideas to which the users converged at. Access to video captures for all the gestures identified in each task is provided in Appendix B.

Tasks 1, 2 and 3 are related to pointing elements of the environment to the team. These tasks were the ones with the highest agreement scores in both scenarios. Participants defaulted to pointing with one or two fingers towards the camera in the general direction of the digital object or trying to superpose the gesture over the object. Figure 5.4 shows the agreement score for the 11 unique gestures identified for the task.

The selected gestures involved pointing directly to the object with one or two fingers, with a stronger tendency for this gesture in the headset scenario, while mobile users defaulted more to tapping motions in the screen. The most important reasoning given by the users for the tapping behaviour was that the motion was *natural* or *common*, especially for a touch screen. In scenario 2 some users also mentioned the naturality of the tapping motion comparing it to touching a screen, highlighting the influence of previous knowledge when translating the actions to a scenario that is similar or somewhat familiar. The tapping motion also included stronger deviations of the gesture, like using the whole hand or exaggerating the pointing motion of the object to make clear the intended selection and to eliminate ambiguity in the selection, a concern mentioned by some users.

A variation proposed consisted of grabbing or holding the object to signify to others that *this object here that I am shaking is the one I am talking about*, to use the words of one user. The mechanics of holding the object varied a lot between users, sometimes using one hand or both, and with or without movement involved after the grabbing motion.

It is also important to mention that the task was described to the users as *pointing* to an

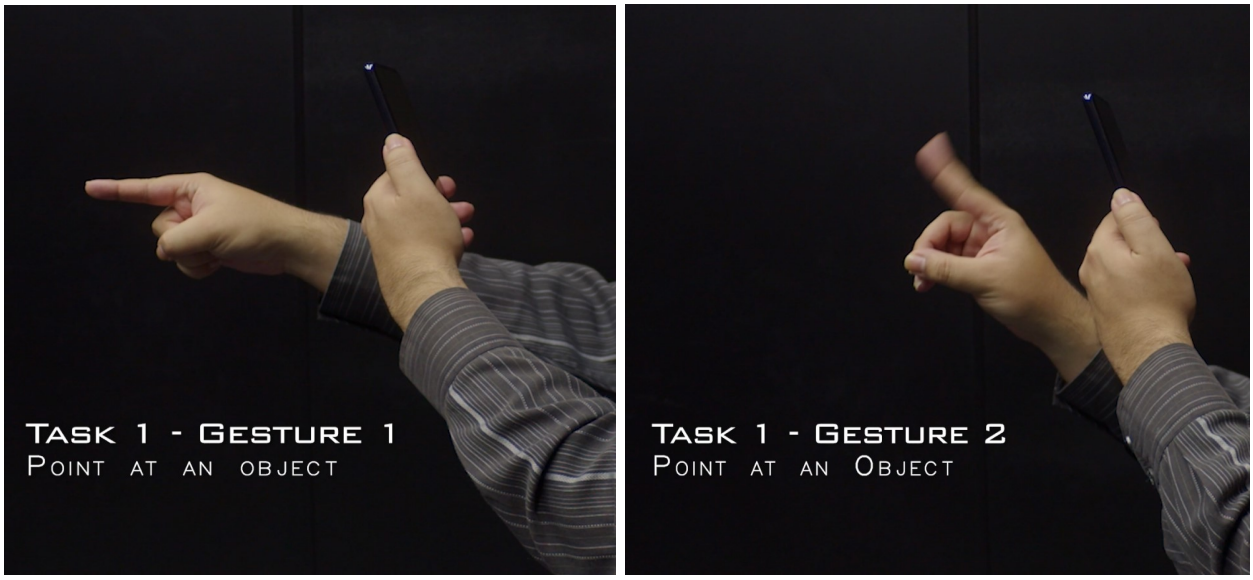


Figure 5.5: Point at an Object - Pointing Index (left) and Tapping Motion (right)

object, which could have predisposed the users to a particular set of gestures. The task was described as such to convey the idea that the action was done for the benefit of another user, and that the main objective was to highlight the object to another person, not only to select the object. Nonetheless, a more neutral term could have been used, like *show*, *mention* or *indicate*. Figure 5.5 shows an example of the selected gestures for task 1, Figure 5.5 (left) depicts Task 1, Gesture 1 (T1G1) : Pointing at the object with the index finger, while Figure 5.5 (right) shows T1G3: Tapping the object with the index finger.

Task 2 yielded very similar results. Participants used more descriptors or directions related to real-world elements. Phrases such as *the one next to the chair* or *the one next to your hand* were common, but these comments were always accompanied by the same pointing gesture. Figure 5.6 shows the agreement score for the 15 unique gestures identified for Task 2.

A significant number of users defaulted to use the whole hand for the pointing gesture, but it was not possible to identify a reason for such a difference in comparison to Task 1. Figure 5.7 shows an example of this gesture. Another common proposal was to draw some figure to enclose the point in space being pointed at, like a circle, an X or some movement of the fingers.

A similar situation was present in Task 3 when pointing to a person. In this scenario, the extended hand gesture was explicitly explained by the participants, who expressed reservations about pointing at someone else with a finger, considering it disrespectful. They preferred to point using the entire hand with the same gesture shown in Figure 5.7 or by tapping on the screen. Otherwise, the same tendencies shown in the previous two tasks were also present in here. Figure 5.8 shows the agreement score for all the 13 unique gestures identified for Task 3.

To wrap up the analysis of the pointing category, it was observed that users defaulted to pointing objects using an air gesture with either the index or the whole hand. Users also commonly referred to their previous experience with touch screens, with a tap in the air or the screen that felt natural. There was not much difference between pointing digital or

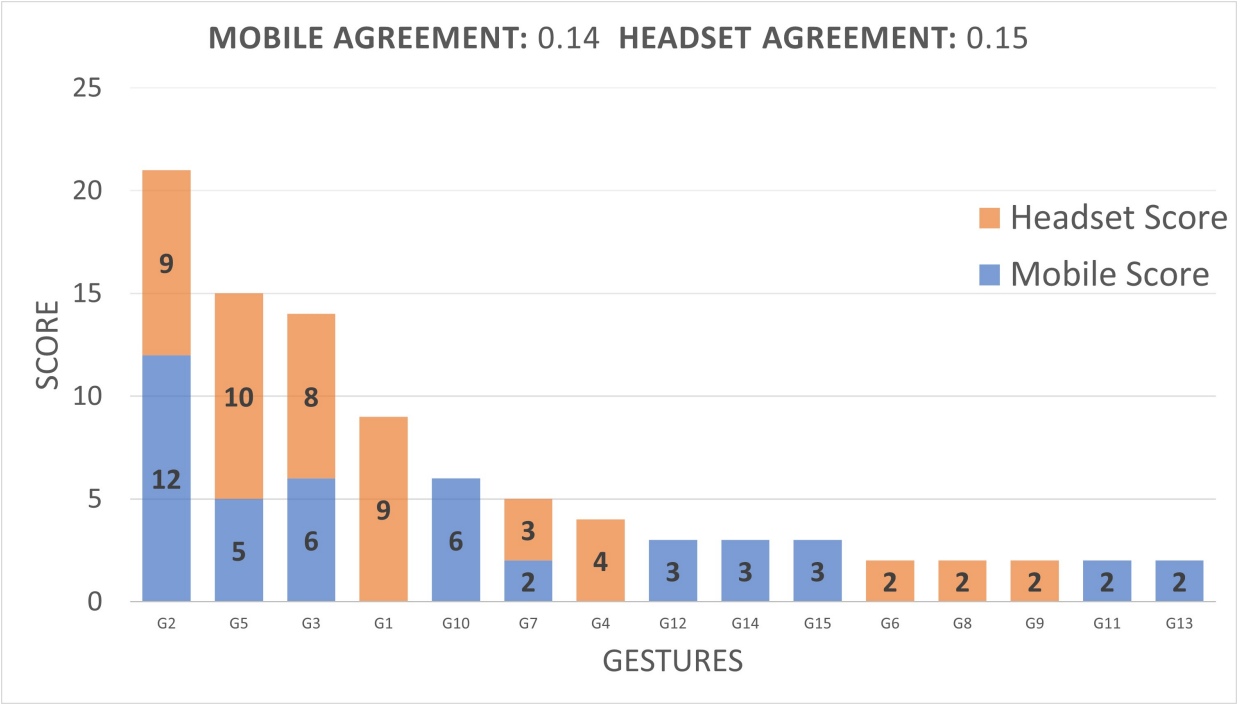


Figure 5.6: Agreement scores for unique gestures in Task 2



Figure 5.7: Point at a place - Extended hand gesture

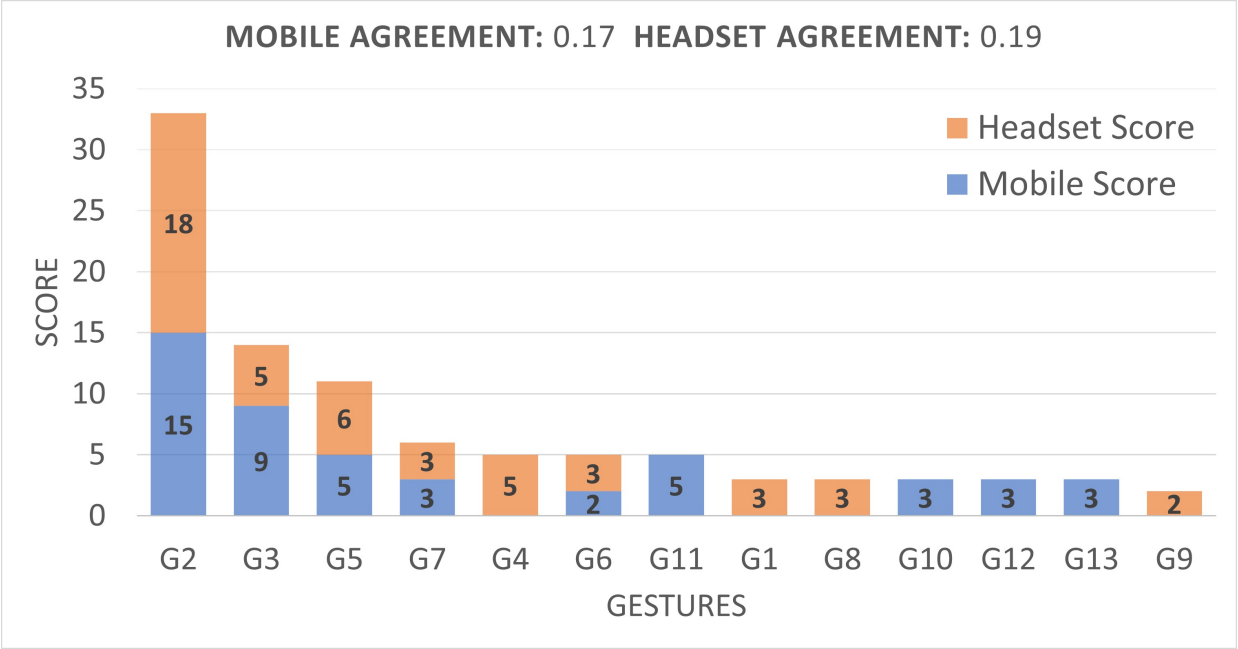


Figure 5.8: Agreement Scores for Unique Gestures in Task 3

physical objects, but several participants had second thoughts and concerns when pointing people, considering the index gesture as rude or inappropriate.

Task 4 required to hold and manipulate an object and was designed to examine how the two scenarios would influence the participants' interaction proposal, especially considering that Scenario 2 provided the freedom to use both hands. There were indeed instances of gestures only appearing in Scenario 1 and others only in scenario 2. The use of mobile phones led some participants to default to a familiar drag gesture over the screen to hold and move the digital object.

On the other hand, the headset scenario strongly promoted the participants to use the perceived physicality of the digital object to try and grasp its contour using the index finger and thumb or even with the whole hand, as shown in Figure 5.9. The next most popular gesture used a simpler approach of grasping the object by completely closing the hand over it or pinching it with the index and the thumb. Scenario 2 appeared to promote participants to select the most complex yet more realistic approach.

Task 5 is the collaborative take of the object manipulation category and was designed mostly for gathering ideas from the users on how to organise the group while manipulating objects. The participants were specifically prompted to explain how they would share a held object or the act of sharing anything in general. In this case, both scenarios converged to the gesture of extending an open hand in the direction of the intended target, either to automatically trigger the sharing action (a very straightforward, abstract action) or as the first step of a process, expecting the other team member to extend their hand and take the object (a more realistic, physical action). Mobile users also converged to the motion of throwing by swiping the object in the tocuhscreen in the direction of the intended target. Examples of all these gestures can be seen in Figure 5.10.

For these gestures related to sharing and manipulating objects the participants proposed

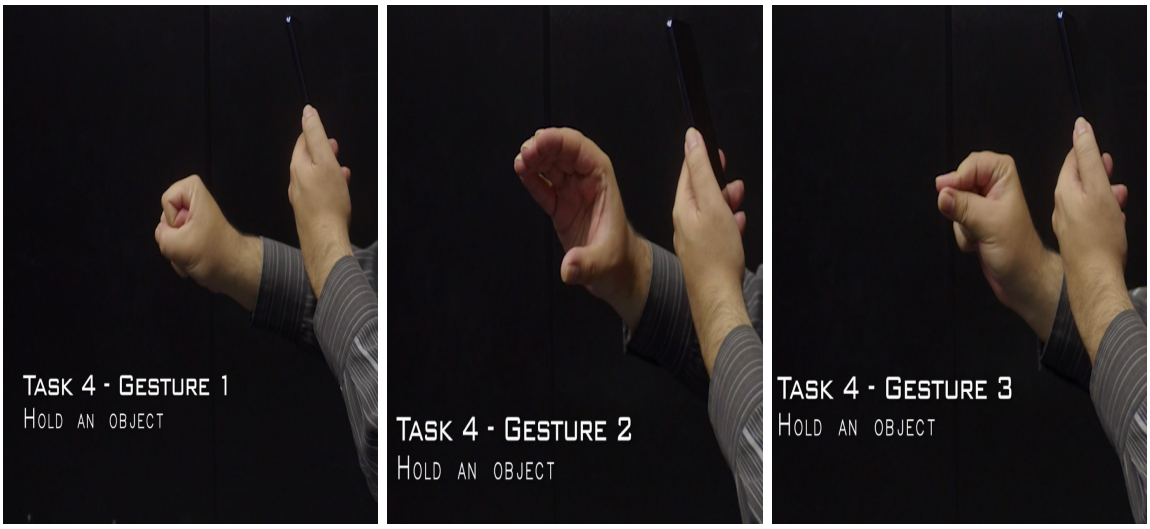


Figure 5.9: Hold an Object - Closed Fist (left), Contour (middle) and Pinch (right) gestures



Figure 5.10: Share an Object - Pass over (left) and Toss (right) gestures

increasingly more complex gestures requiring full movements or patterns to convey the intended meaning (which are harder to show in static figures). Movement ranged from simple patterns like swipes or tosses that only required a direction or a reference to the target team member, while others proposed complex series of movements normally involving the other user in the action, with specific protocols required to initiate the sharing of an object and its receipt from the second user. Figure 5.11 shows the agreement scores for all the gestures identified in Tasks 4 and 5.

Tasks 6 and 8 corresponded to taking an object in and out of the *private workspace* of the participants. The shared and public space metaphor was an interesting concept that appeared in literature to emphasise the need to differentiate between public and private spaces in shared experiences. The shared versus *private workspace* creates a boundary for each user to be able to keep work and experimentation as private work and be able to control what is shared with the team and what is not. In terms of interaction design it also offered the opportunity to understand how users would understand this concept, if at all, and if it was possible to converge into a set of gestures to represent possible actions needed for this scenario. It was decided to focus on the process of moving from and into the private space and how can this be signalled in the shared experience. In this case, both data gathering scenarios clearly converged to different gestures.

Both converged sets were similar in nature and consisted of moving the object with one hand to and from the area shown to participants as their *private workspace*. The difference appeared when participants in the mobile scenario saw a zone in the border of the phone's screen and dragged the object there using a hold-and-drag gesture. Few people took the object with their hand, and if they did, they did not consistently use the same gesture proposed in Task 4.

On the other hand, headset users saw a zone in their physical space and moved the object there, sometimes holding it using the exact same gesture proposed in Task 4, but not consistently. Other times they would use a completely different gesture to hold and drop the object or would use a different one related more to push the object into the zone or drag it close to their own person. Figure 5.12 shows examples of the converged gestures for both tasks.

This distinction between scenarios is very probable due to the way the private workspace was shown in each scenario: a 2D space on the screen for Scenario 1 and a 3D area near the user for Scenario 2. This could have prompted the participants to use the screen rather than an air gesture. It is also probable that the screen interaction would have been one of the most prominent results even if both scenarios would have shown the same representation of the tasks, considering how for tasks 4 and 5 mobile users also defaulted to interactions using the screen despite the mostly 3D representation shown to them in the application.

The idea behind Task 7 was not necessarily collaborative in nature, mostly exploring a common action in any other software that could be expected by users in the functionality of *WorkshopAR*. Its implications in the coordination of action when manipulating objects could also be discussed. In the end, Task 7 represented one of the less agreed upon sets, and showed a variety of approaches to signal the process of undoing the previous action, but the most agreed upon comment among both scenarios was that such an action could better be implemented via a button or option in a menu, and not linked to a gesture, either in the air or the touch screen. This is important because the idea of unnecessary gestures became

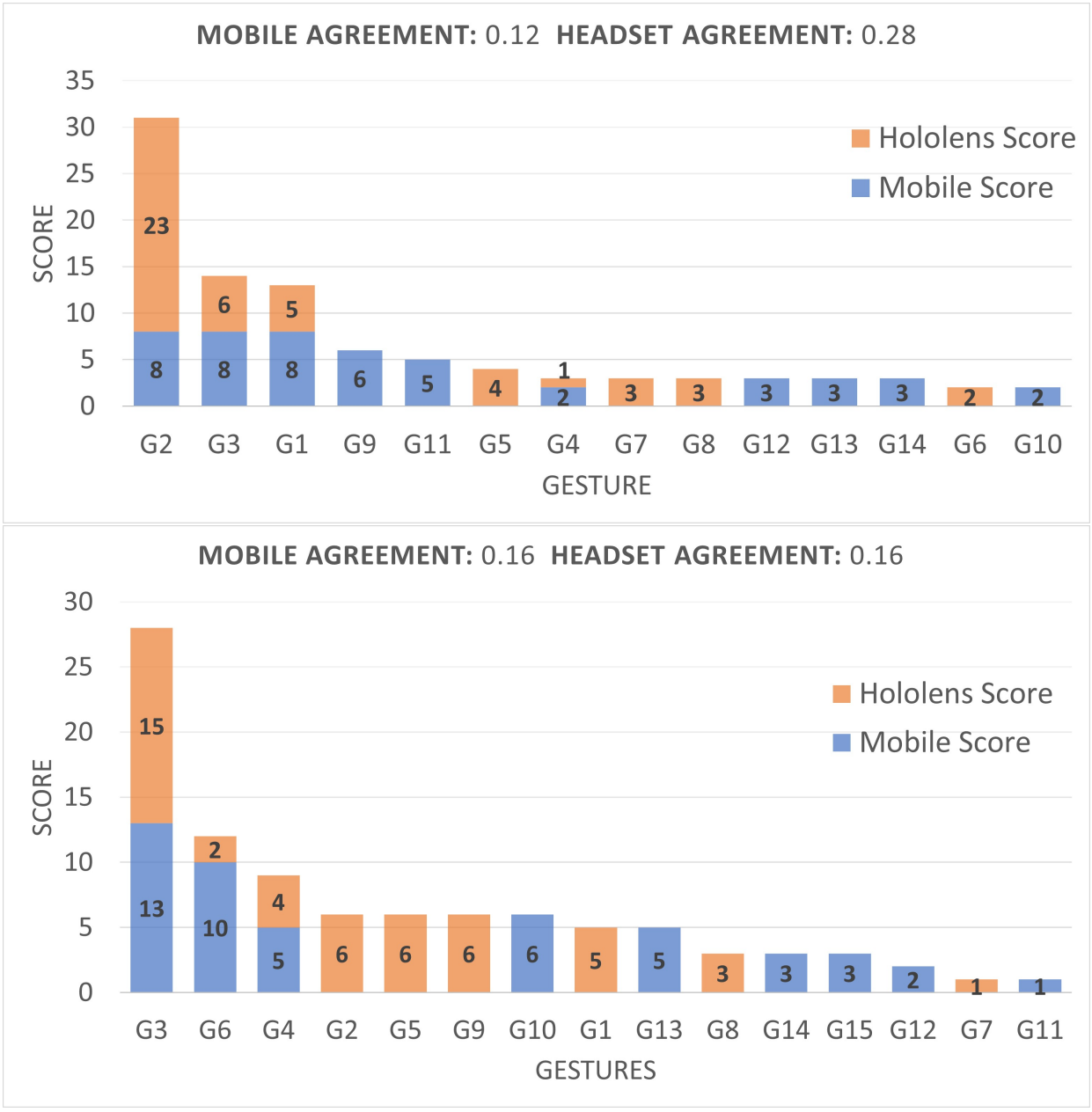


Figure 5.11: Agreement Scores for Unique Gestures in Task 4 (top) and Task 5 (bottom)

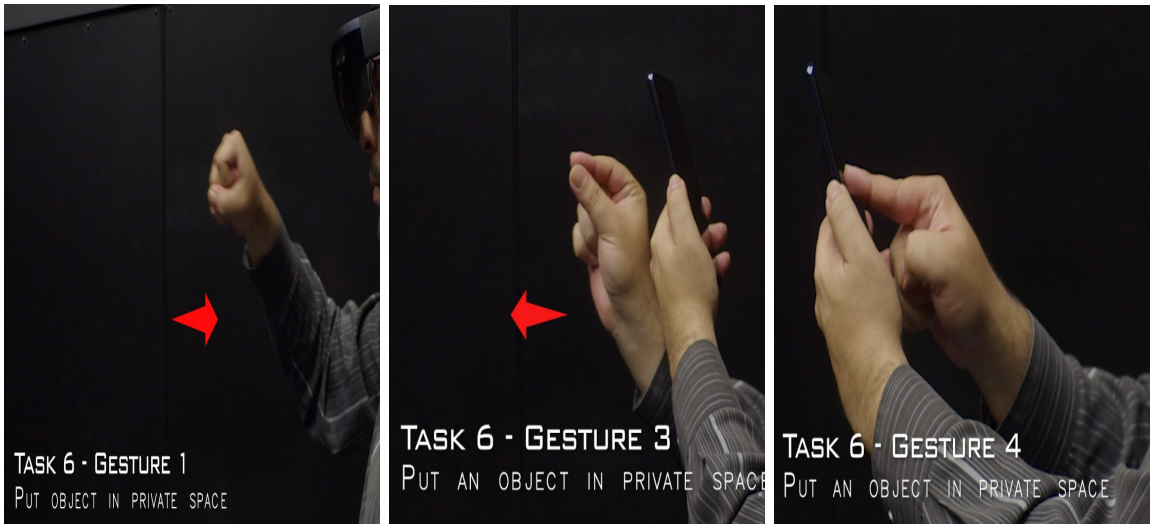


Figure 5.12: Put an Object in Private Space - Fist hold Inwards (left), Pinch Hold Inwards (middle) and Screen Swipe (right) gestures

more prevalent in the following tasks. Figure 5.13 shows some of the most common gestures proposed for the task, while figure 5.14 shows the distribution of the agreement score for all 22 gestures identified.

Tasks 9 and 10 asked the participants to vote in a debate or answer a multiple-choice question. The tasks were designed to identify differences in interaction when the participants had to deal with a clear user interface in comparison to a more physical selection involving objects in the digital space. A similar situation to that of tasks 6 and 8 appeared here when presenting to the users a more physical representation of the tasks in comparison to one mostly based in UI. Within these tasks, results were consistent, and participants in Task 10 proposed more air gesture and with more complexity.

Task 9 showed a static menu on screen to represent the voting process, and as expected, it converged to simple selections over the user interface, normally a tap in the screen or a pointing gesture in the headset. Major distinctions consisted in changes in the pointing action, like using two fingers instead of one. The biggest variants used exaggerated version of a tap, like a stamp with the whole hand or a punch. Figure 5.15 shows examples of the selected gestures for this task.

For Task 10, pointing was still the most common gesture in both scenarios, probably because the 3-dimensionality of the objects promoted air gestures, even in Scenario 1. Holding the selected object was the other most common proposition. Like Tasks 6 and 8, the holding gesture was not consistent with the ones used in Tasks 4 or 5. Yet, both scenarios converged to the same holding gesture, particular for this task. It consisted of holding the contour of the object from the top. Because in Tasks 4 and 5, the holding gestures were accompanied by the expectation of having to manipulate the object in some fashion, participants probably preferred a more precise grasp that allowed easy rotation and inspection. Task 10, on the other hand, only required to signal the selection of the object, and probably merited a simpler hold. Figure 5.16 shows examples of the selected gestures for Task 10.

A possible speculation is that the way the objects were shown to the participants affected

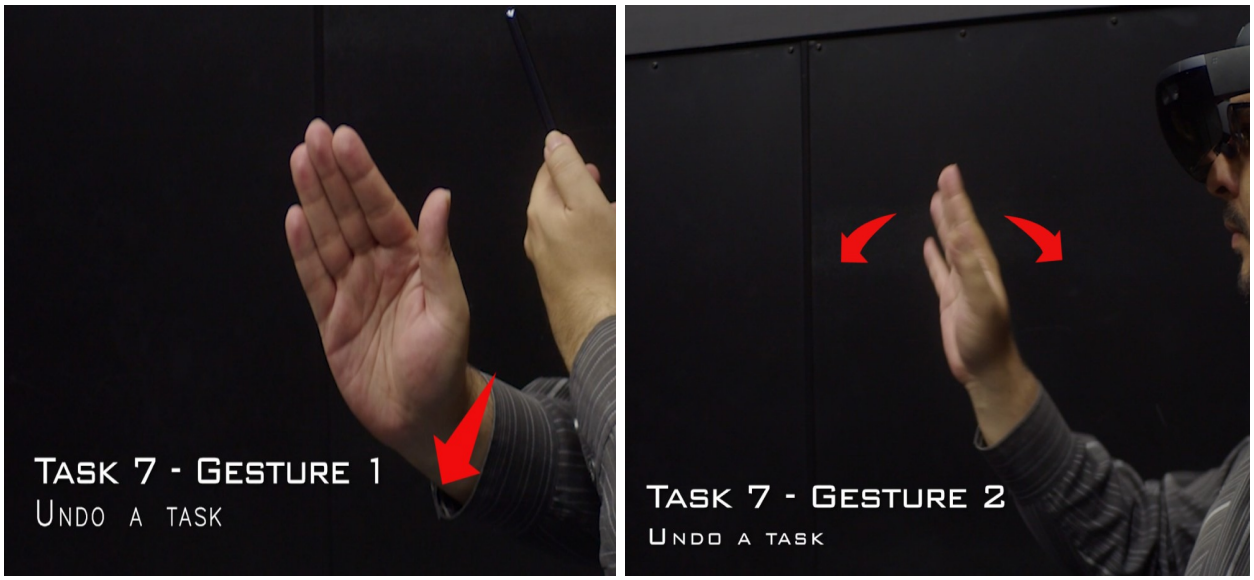


Figure 5.13: Undo a Task - Push Sideways (left) and Wave (right) gestures

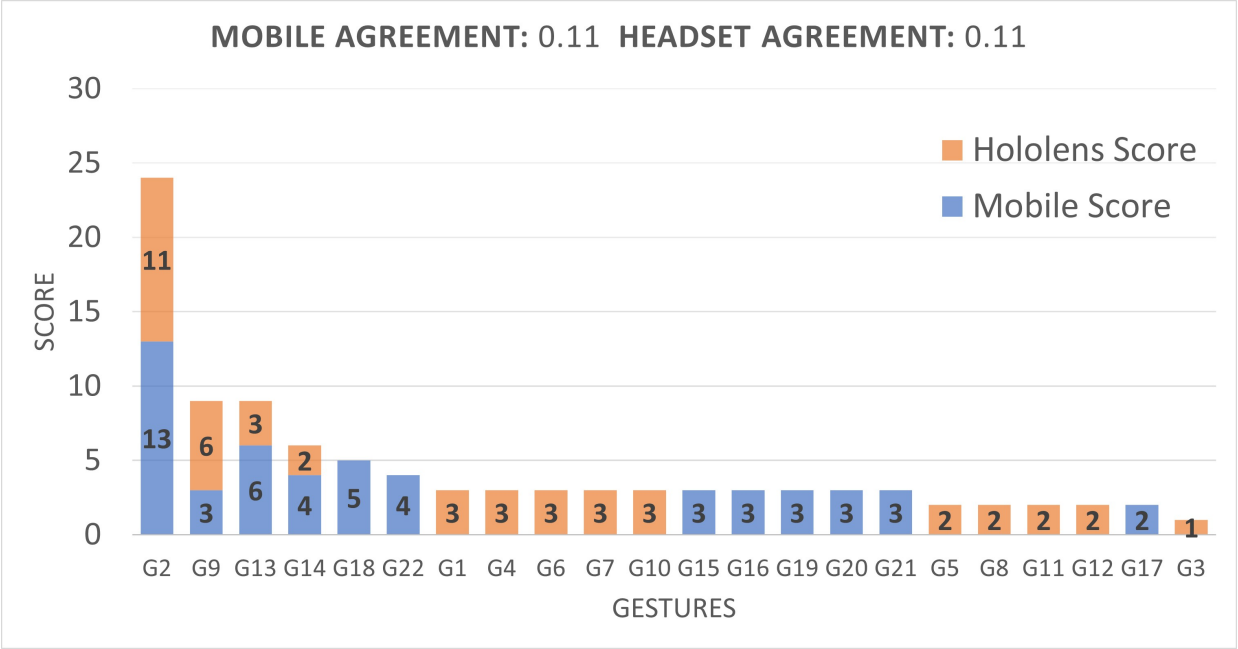


Figure 5.14: Agreement scores for unique gestures in Task 7

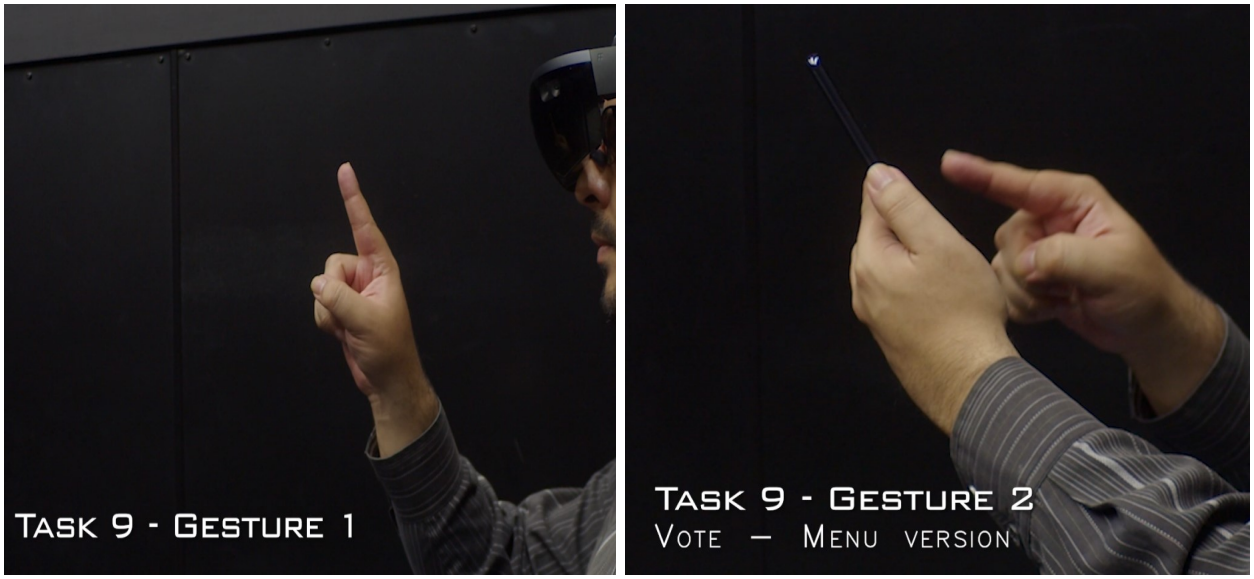


Figure 5.15: Vote in a Static Menu - Air Tap (left) and Screen Tap (right) Gestures

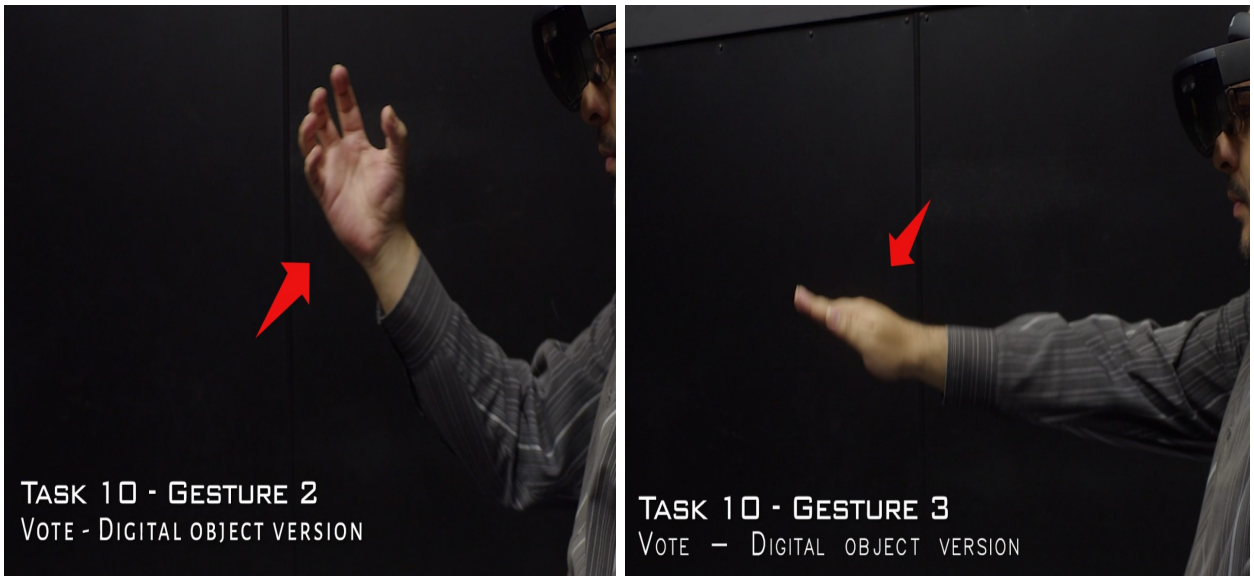


Figure 5.16: Vote with a Digital Object - Contour Hold (right) and Object Tap (left) Gestures

the decision-making process. The objects were anchored to the table or surface where the visualisation was taking place, which probably promoted a natural reach-and-take motion. If the objects were floating in space or shown in a more abstract manner, reactions might have been different. Figure 5.17 shows the agreement score distribution for both versions of the voting tasks and all the gestures identified.

Tasks 11 through 14 presented activities common in managing a group, like organising a conversation, asking for attention, or signalling a pause in activities. These tasks presented the higher variety of proposed gestures, mainly due to their abstract nature and because participants commented they represented a process more than a simple action that could be triggered by a gesture.

Tasks 11, 12 and 14 converged to simple air gestures that commonly represent their respective actions in real life. Asking for attention, either for teammates (Task 11) or for every group (Task 14), was represented by raising a hand, often with the variation of waving. Signalling a pause in participation (Task 12) was represented by showing the palm of one hand in a stop motion. Figure 5.18 shows examples of these gestures.

All these cases are good examples of proposals that would pose a conflict in an actual interaction design because they are practically identical, the main variation only being the height of the gesture or what side of the hand is shown to the camera. Among several other proposals for Task 4, Task 9 and Task 10, there is a conflict between natural, significant gestures, gestures detectable by the technology and complex gestures that make sense to a human but would add too much complexity to the process guided by a software.

Another interesting observation for these tasks was that a lot of participants also converged to a form of voice command to ask for attention or to communicate any status of the activity, arguing that it would be more natural to simply talk with your teammates if they are near, rather than to rely on the software to control the whole action.

Task 13 represented an action meant to convey order to a group discussion, and a form of control of who was speaking or guiding the conversation. The results show similarities to the previous examples, with participants arguing that the tasks were suitable more for a process than a single triggering gesture, effectively dividing the task in two distinct steps: a gesture for stopping someone from talking, then another for giving someone the turn to speak. Few participants tried to give a gesture that encompassed the whole process, and it was always a composite one, made of distinct gestures or movements for each part. The gestures for stopping people from speaking were similar to the gestures for Task 12, and pointing at people was the preferable method to signal the turn of speaking, like the gestures for Task 3. Figure 5.19 shows the agreement scores for all the gestures identified in Task 13, while Appendix B contains video records of all gestures, especially for those that are hard to show in printed form.

Analysis and Conclusions

Participants also provided an extensive catalogue of ideas and commentary that accompanied the proposed gestures. These ideas and conversations were compiled and analysed using transcripts of the recordings. The main ideas discussed were organised in major categories that contextualised each participant's proposal or that promoted some form of discussion around the methodology, the setting, or the technology.

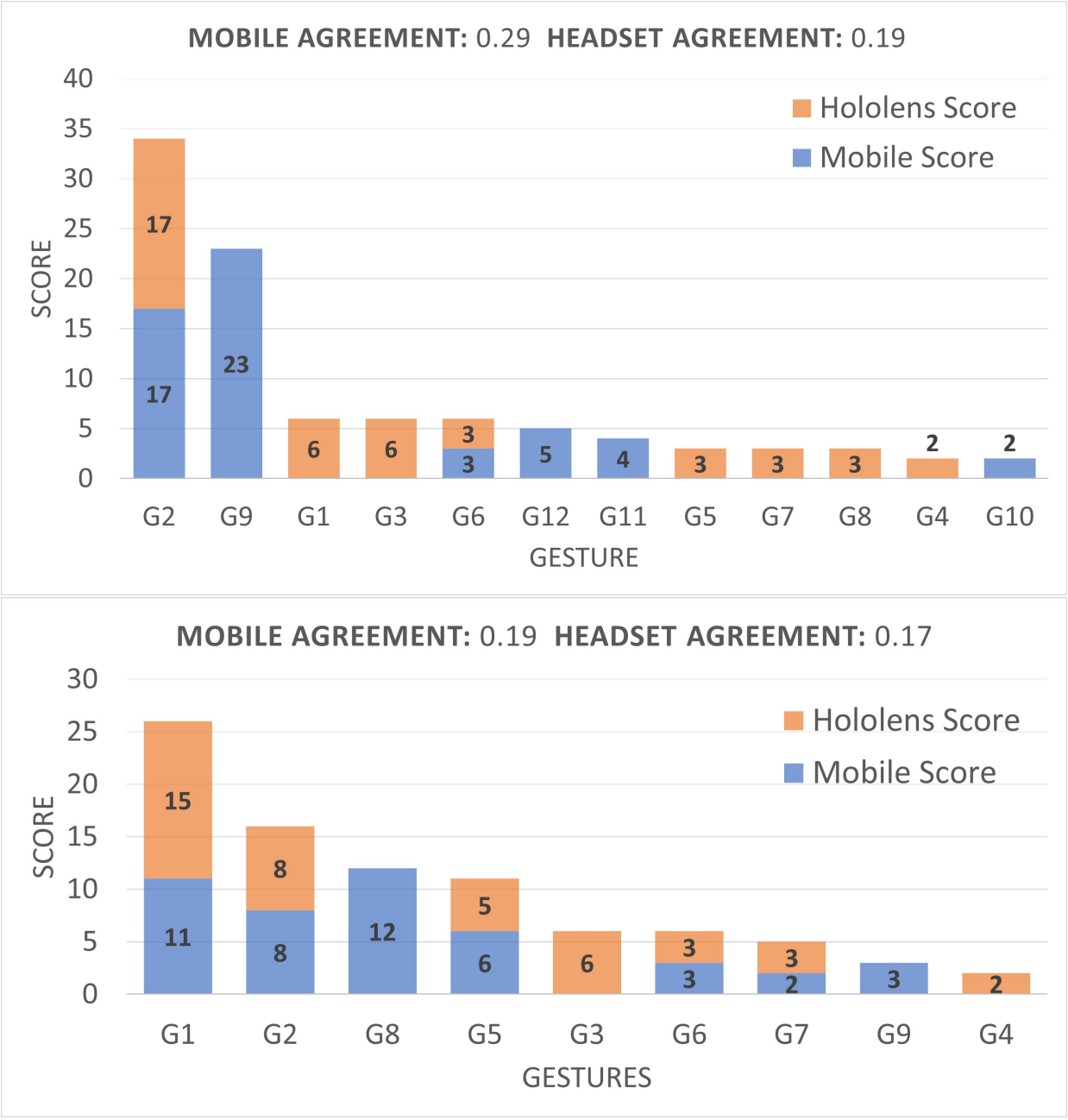


Figure 5.17: Agreement Scores for Unique Gestures in Task 9 (top) and Task 10 (bottom)

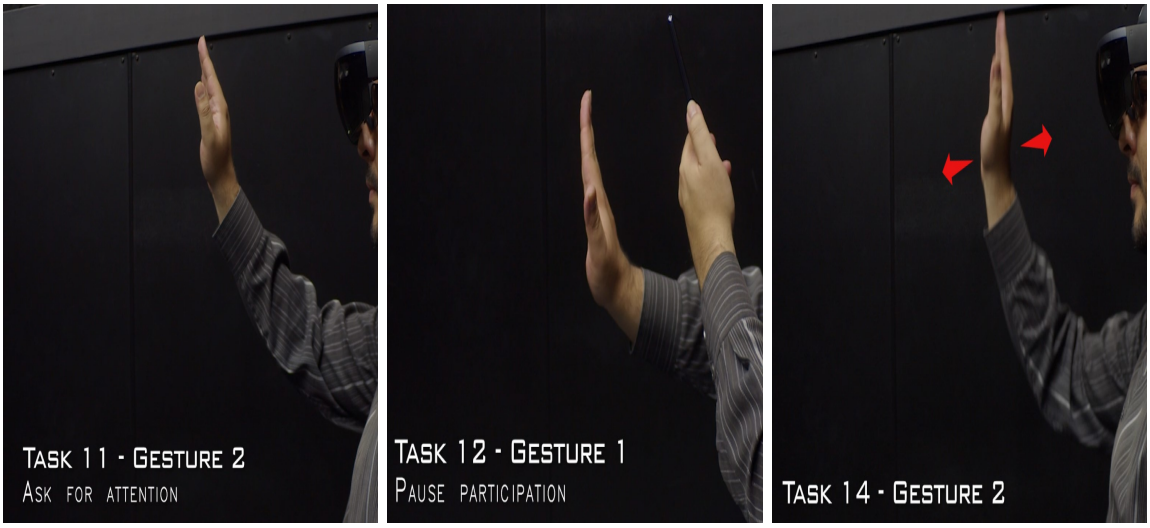


Figure 5.18: Raising Hand Gesture for Task 11 (left), Task 12 (middle) and Task 14 (right)

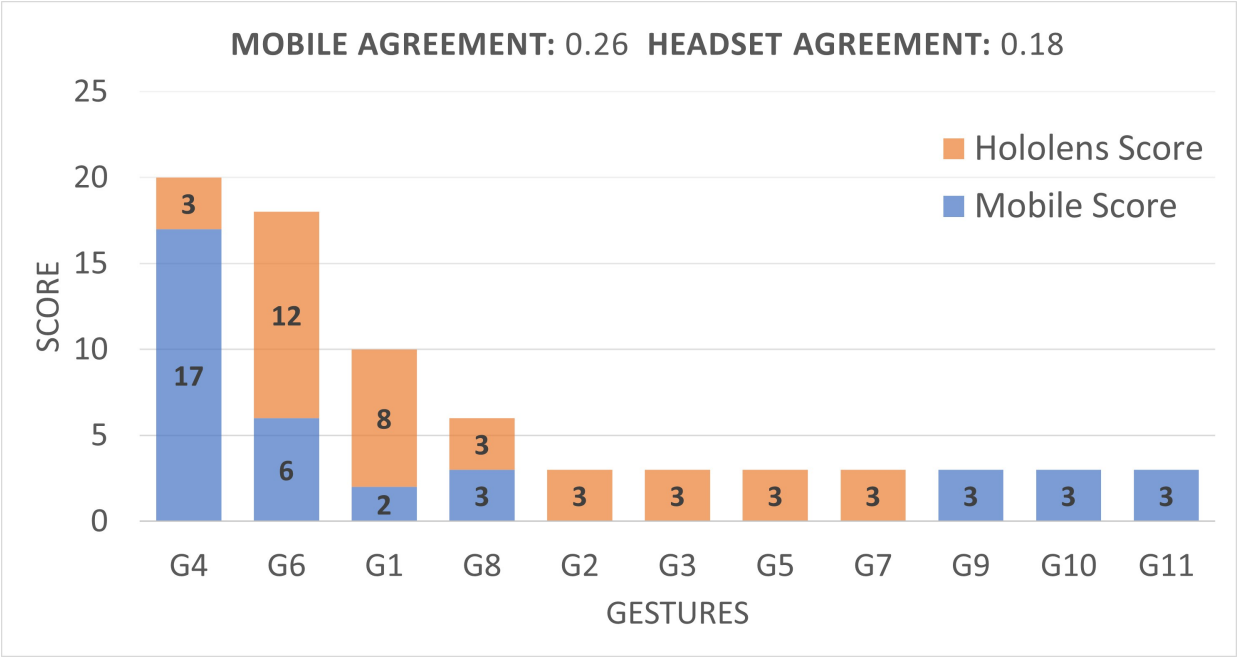


Figure 5.19: Agreement Scores for Unique Gestures in Task 13

Some elements of the research methodology, or the instruments used, influenced in some way the decision-making of the participants and prompted or facilitated the same types of gestures or the same type of ideas and issues to arise. For instance, participants assigned to Scenario 1, which used a smartphone, defaulted immediately to the screen as their main medium of interaction. By far, the most common intervention that the researcher had to do during the data gathering was to remind participants in Scenario 1 about air gestures, and when participants referred to some gesture to be *natural* or *logical* to solve a task, most of the time they were performing a touch gesture in the screen.

Of all the participants interviewed, 60% reported not being familiar with AR technologies, which can translate to most of them feeling more comfortable or seeing as more logical to use a known touch gesture in the screen to perform any task. People that reported to be knowledgeable of AR also reported to understand how air gestures work and how they are recognised by the technology, as well as being aware of the limitations they possess, which derived into preferring touch interactions or UI elements because they recognised air gestures as impractical or too difficult to be recognised.

In comparison, headset users in Scenario 2 had no other option than to propose air gestures due to the nature of the technology. We can hypothesise that given a more recognisable mean of interaction, like a controller with buttons, participants would have also defaulted to use it. An interesting aspect about the air gestures proposed by headset users is the realism of the actions. Hold gestures, for example, would consider the size and contour of an object and its position in space.

Finally, the way tasks were presented to the users through the application also affected the proposals. Some of the participants based their gesture mainly on the animation shown to them, like the movement of objects or some visual effects meant to signal or represent things, like a selection or someone performing an action. Similarly, any UI element predisposed the participants to think about UI interactions. Closely related to this, some participants assigned to Scenario 2 were completely fixated to the default select gesture of the HoloLens headset (a pinch with the index and thumb), which had to be taught by the researcher at the beginning of the session to facilitate the interaction with the device.

Independent of the scenario, some other common situations arose when participants tried to explain or justify a gesture during the think-out-loud activity. The most common discussions emerged when the participants themselves found issues or flaws in the hypothetical scenarios created by them to explain or understand the gesture proposed. These were very valuable pieces of information because they showed how the user expected something to work and how they would use gestures in a real scenario. Some outstanding examples were:

- Participants felt awkward with conversations mediated by technology. The extra steps in the communication process were seen as a problem or in need of too much justification to feel natural.

- Participants expect the technology to detect a lot of social cues used in normal communications, such as sounds, gaze, and facial expressions.

- Participants not familiar with AR interactions felt more comfortable with gestures that mimic actions in real life or conveyed an understandable meaning, despite more abstract

or simple gestures being easier to use. In contrast, more familiarised participants proposed simpler and more concrete gestures (like touches, taps or drags).

This user-centred design exercise gathered 24 participants to identify natural air gestures for interaction with an augmented reality application in a collaborative setting. The participants proposed a total of 478 gestures to cover 14 different tasks related to interactions with teammates and sharing a common goal. Of those gestures, 195 were unique propositions organised based on level of agreement to make the final selection of 39 gestures, which represent what the participants considered the most natural means of interaction with AR technologies either using a smartphone or a headset device. The resulting set of interactions is a useful tool to start thinking in the design of a collaborative AR application and the issues that must be solved in a concrete solution such as *WorkshopAR*.

This research was based on the premise that collaboration is an important aspect of the value proposal that AR can convey. With the advent of new consumer products available on the market, it is necessary to understand how to use this technology in a social context, and how the process of communication itself can change when similar tools gain more popularity and mass adoption. Communication itself is a big aspect of any collaborative task, and it is important to learn more about how interactive technologies mediate those communication processes, how to mitigate the issues that will arise and capitalise on the benefits. Particularly, given the context in AR that this project holds, it can be interesting to research and analyse what it means to augment communication, collaboration and social interactions.

5.1.2 Implications for the implementation of WorkshopAR

The previous research effort had a broader objective of understanding and identifying natural approaches that users propose to interact with AR technologies. The research showed complex interactions when offered a hands-free form of control in comparison to the simpler gestures present in the common language being developed around these types of controls. The metaphors and approaches currently available in the industry are not yet widespread enough in the market or among the final users, which prompt users to have more complex or elaborated expectations of what the technology is capable of.

On the other hand, when users are presented with a mobile, touch-based device (a smartphone), the situation reverses, and the users start to rely on their knowledge and previous experiences with touchscreens, expecting or defaulting to gestures and interactions that are common in the mobile design environment. The conjunction of these two scenarios creates a situation in which users could be completely unfamiliar with the technology and would need a substantial learning period to properly use an app, or could be very familiar with the device, which facilitates learning but also has to take into account expectations and behaviours that could either inform or clash with the current implementation.

By analysing this information in the context of *WorkshopAR*, some important conclusions informed the future design and development process:

First, from the selected set of gestures, it was possible to observe that both the touch screen and headset scenarios converged to gestures that were similar to or compatible with each other. There were few instances of radically different proposals for each scenario. The selected gestures were at the top or near the top of the agreement ranking and consisted



Figure 5.20: Interaction Examples with the Meta Quest (top) and the Apple Vision (bottom)[1]

mostly of simple static gestures (a tap or a point selection) or common movements (swipes, waves of pinches). The commonality among these gestures is that they worked the same or at least very similar in both testing scenarios and could also be represented in a full air-gesture representation with little or no change. These first responses or initial variations to the first responses reflected a tendency for users to default to known and tried approaches to interaction.

This behaviour is supported by the design implementation followed by modern (as of the writing of this document) AR-able products such as the Meta Quest 3 and the Apple Vision, which opted for simple and recognisable gestures like taps and pinches, even when the hardware is capable of robust hand recognition. Figure 5.20 shows some examples.

For the development of *WorkshopAR*, this indicates that the interaction design can focus on a single set of gestures for both mobile and headset deployment, opting for a *touch screen approach* that can be equally implemented on a screen or in a floating style UI. This would

[01] Images extracted from https://www.youtube.com/watch?v=Exu7r2vZpcw and https://www.youtube.com/watch?v=dtp6b76pMak

present familiar interactions for all users and would simplify the multi-platform approach.

Second, the data shows that air gestures work better as abstractions, even when strong hand-recognition capabilities are present. Several users reported how unnecessary it felt to perform a complex gesture in a 3D space when a simple touch on a screen or on a UI option would suffice. This was especially apparent in the more process-driven actions like voting in a debate or pausing the current activity.

Given this observed behaviour, it was considered as an opportunity to simplify the general interaction design of *WorkshopAR* to consider only standard gestures. Although air-gestures represent an interesting development and research topic, for the overall goals of *WorkshopAR*, they would divert time and resources that would not properly translate into data for the proposed research questions related to collaboration and Technology Enhanced Learning (TEL). A simple set of gestures supported by a clear UI promoted a simpler production and a more straightforward learning curve for the users.

Third, it is important to focus more on user-centred processes rather than software-driven ones for the functionalities of *WorkshopAR*. This can be supported by the general reaction of the participants to the most complex tasks tested like voting and asking for attention. Although every task converged to a distinct set of gestures, comments and ideas exposed confusion and frustration when trying to understand or justify the proposals for these types of tasks. The main struggle related to linking what was viewed as a complex process to a single trigger action. Concerns on how to implement such gestures in a real application were also voiced. The data also showed that some participants found it impractical or simply wrong to communicate to other people through the application when they were sharing the same space and were at talking distance.

In summary, the research process on collaborative gestures informed several aspects of the interaction design of WorkshopAR: the expectations that users have with the technology, the best road to approach the most physical aspects of the interaction design, and how to promote the ideas at the core of learning goals of the application. In general, this approach can be summarised as:

- A focus on simple gestures that prioritise touchscreen recognisable actions.
- Rely on processes guided by the users and not the app.
- Promote structures rather than enforcing them.

5.2 Implementation Process

5.2.1 First Development Iteration

The main objective of the first iteration was to create a deployable test for the shared AR experience. Rather than approaching any of the use cases, the objective was to test different technologies and run trials on how to create the multiuser interaction. Four objectives were established for the iteration:

1. Create the *digital room* concept based on scanning the physical space and providing specific configuration parameters.

2. Create the participant's profile by identifying the most important data needed for configuration and information display in the *digital room*.

3. Open the *digital room* for a session and allow participants to connect, acknowledging the interchange of information over the network and the visualisation needed on AR.

4. Test the creation and interaction with digital objects during the *work session*.

The iteration focused more on testing different technologies and understanding the deployment of an AR solution over a network. Once the most relevant aspects of the infrastructure were understood, development moved to prototyping of the main usage loop, which can be specified as:

- Joining a configured *digital room* and visualising other participants in the session.
- Creating a *workspace* for the session.
- Adding and interacting with digital objects.
- Pointing at digital objects, other participants and other physical elements in the physical space.

These objectives were considered as major milestones to achieve during the iteration and were used as markers for progress along the six months of development that the iteration approximately took. The development of each milestone was followed by a set of unstructured tests to gather quick feedback and incorporating changes and adjustments that could feasibly be developed in parallel to the advancement of the other milestones. Important points of change that were not possible to quickly incorporate or that required a major pivot in development were logged for the next iteration or even tagged as analysis points for future work.

The following sections will explore the results obtained for each milestone and the data gathered in each testing phase. It is important to remark that the process itself was not as structured or as sequential as explained. Although there was a clear plan and a tangible set of goals guiding the process, each milestone was worked on and tested in parallel and at different points of development, keeping a constant communication loop with testers and students but without following any formal sequence of steps or a staged process.

In terms of the case study, the iteration ran along the first half of the observed cohort, offering the students the opportunity to interact with the creation of the *digital room*, the tools to manage the *work session* and the initial steps to create the interaction with the play objects. This process was gradual and constantly changed in response to the feedback given by the students, yet, the analyses in the following sections are shown in isolation to facilitate communication and exposition.

The Digital Room and the Workspace

The concept of the *digital room* was defined as the physical space used to hold the *work session*, represented in the app as the network session that coordinates all the participants

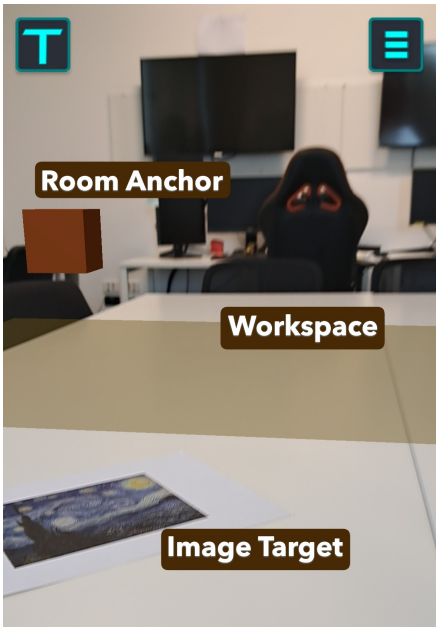


Figure 5.21: Basic Configuration of the Digital Room

and the digital objects. The *digital room* itself is constructed and coordinated by several elements of the architecture (see Section 4.3.3), and is not centralised at all, neither in terms of processes nor software components. Nonetheless, this architecture is transparent to the user, who only needs to understand the *digital room* as a digital space that can be entered to initiate the session, and that holds all the digital objects needed to work.

The *digital room* hints at structure without enforcing it and indicates that a *work session* is running. If a user is not working, then that person shouldn't be in the *digital room*, but without leaving the physical space shared with the other teammates. Hopping between *digital rooms* acquires the meaning of getting in and out of different workflows, each one compartmentalising goals, resources and results, something hard or even impossible to achieve in a physical sense.

Another interaction with the *digital room* is to anchor concepts and ideas to physical elements. It is a principle also linked to flexibility, to make the users think about allocating a space suitable to work and to gather all the needed resources, but allowing the use of any type of space, not only a literal, physical room. Any space could be augmented to fit the needs of the *work session*.

The idea of collaborative augmentation is also at play here, the users can establish a link between the selected space and all the digital information selected, adding a layer of information to the space that can signify whatever meaning the users want it to have (i.e., a wall for ideas, another for issues, and a third one for opportunities). Figure 5.21 shows the basic configuration of the *digital room* that is created at the beginning of the *work session*.

For the technical implementation it was also important to introduce the concept of the host. The implementation followed for the Lightship service (see Section 4.3.2) required a user to act as a host for the network session, since it was decided that the network architecture would follow a serverless approach to facilitate development.

There was the possibility to completely remove the terminology of a host from the side of the users since the concept was only important for the technical implementation, but a couple of ideas made it worth to use the term as part of the user experience:

- Users are familiar with the term in the context of video calls or video conferences (like zoom or Microsoft teams). The idea of *hosting* a meeting or the responsibility of *making the call* is understandable to the users. Comparing the work session with a video conference could be beneficial for understanding the structure of the activity, although it also proved to bring some baggage with it as discussed later.

- It prompts the idea of designating roles to each participant and to allocate tasks and responsibilities.

- It made the process of creating and launching the *digital room* clear and easy to explain because a lot of known metaphors could be used (like the video call or being the host in a room or house).

The host user only needs to select the *digital room*creation and provide a name, which acts as a unique ID for that *digital room* in Lightship, as shown in Figure 5.22. On the other hand, a client user can search for all the available *digital rooms* created so far for *WorkshopAR* and join any selected one. In a more realistic scenario, in which several groups would be working at the same time, it would be necessary to implement more tools for users to filter and search a *digital room* given its ID, as well as means to compartmentalise the creation of a *digital room* inside bigger logical units like classrooms or workshops, this to offer an easier and smother experience for several students at the same time using the application.

The other responsibility of the host is to establish the goals for the session, although this step is not necessary for the activity to continue. It could be the responsibility of the role to manage the goals of the session, either by tracking their progress or by updating the goals as the session progresses. These activities, and the role of the host, are for the group to discuss, organise and implement. All the other technical responsibilities of the host, those related to the coordination of information through the network, are done at the backend of the software, and thus are completely transparent to the users.

With this process the *digital room* is created, and the users are now connected through the network, but the visualisation has not started. Both host and clients need to scan the configured target image with the camera to anchor the *digital room*'s shared origin. Simple QR patterns are normally preferred for this step because they are easy to detect, but any image can work to configure the *digital room* with any resource at hand. Using an image that holds meaning for the group or the current activity is also encouraged.

Scanning the image will establish the origin point of the *digital room* for the local user and coordinate the current state of the room (other participants, play models and annotations). The origin point is also represented by a digital object that can be interacted with to get the status of the *digital room*. Figure 5.23 shows the emergent menu upon interaction with the room anchor. This is the view of the host, who can add and remove goals. It is also possible to give the option for the client to have the same ability to manage the goals of the session, once again giving the option to decide how much or little structure they want to implement in the group.

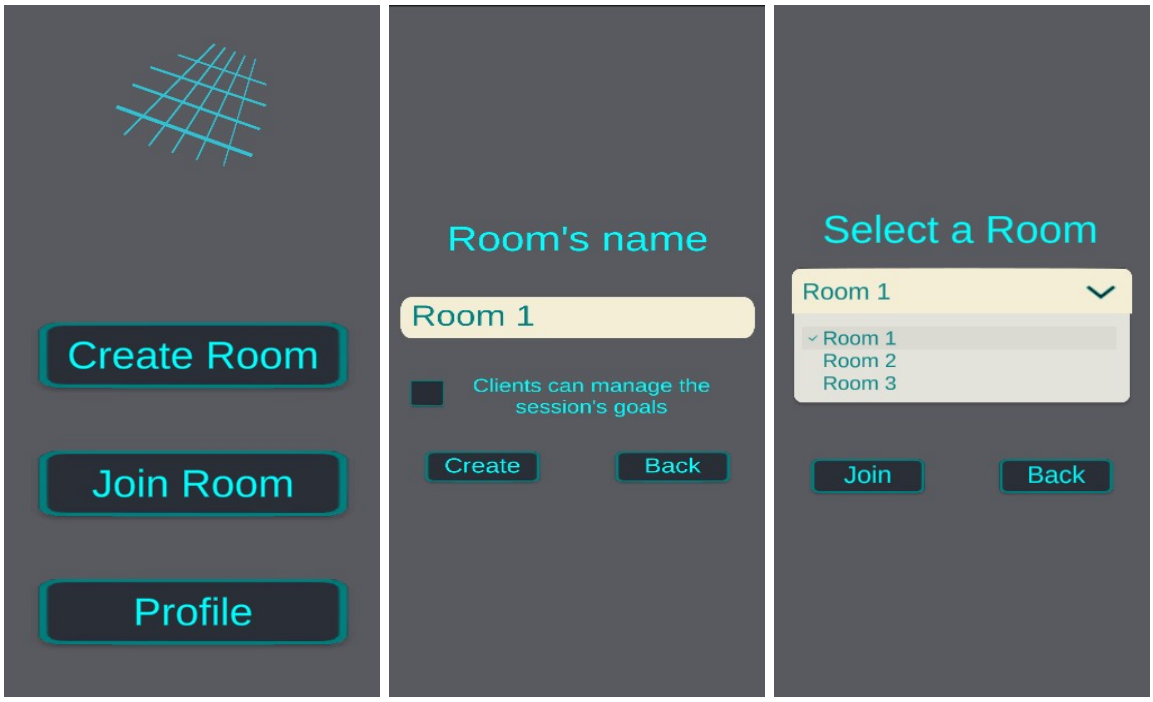


Figure 5.22: Interfaces for Creating a Digital Room (left, middle) or Joining an Existing One (right)

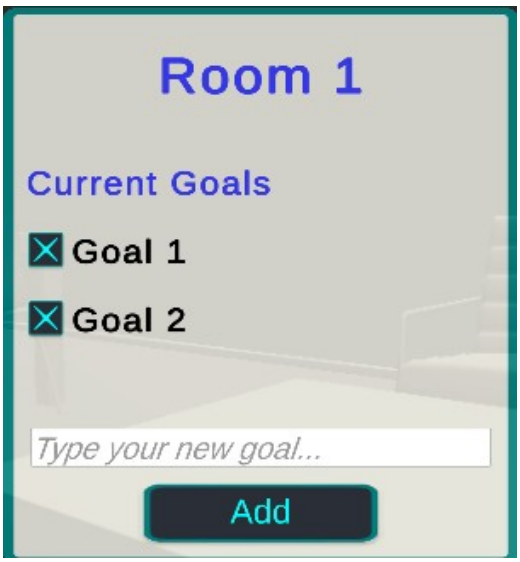


Figure 5.23: Room Information Menu

The final responsibility of the host is the configuration of the *workspace*. If the *room anchor* serves the purpose of indicating that the session in progress, then the *workspace* serves to delimit the interaction area of the *digital room*. The *workspace* is a simple plane that holds all the play models added to the *digital room* during the session. It helps the users to position the objects in the space and focuses the attention of the group into a specific point, avoiding a typical problem in AR where is easy to *lose* objects or menus in the surrounding space when they are not directly on view (Brudy, 2013).

Other possible designs for the *workspace* were considered, specially from the technical implementation point of view:

- Using the detected planes in the room the way they were detected, relying on the output of the *Plane Manager* provided by ShareAR.
- Using a more complex representation like a table or a whiteboard. The model could originate from the target image like the *room anchor*.
- Letting the users position the workspace in the same way they would position an annotation, relying on the *Raycast Manager* provided by ARFoundation.

The final implementation used the *Plane Manager* but did not totally rely on the information detected from the physical space. In the first instance, plane detection (as implemented by most AR frameworks at the time of development) continuously improves the detail of the plane by iteratively merging the features detected in the space. It was considered that the opportunity to have a quicker setup of the room can be beneficial in the context of the classroom.

Second, it was important to not rely completely on the physical layout of the room to encourage the group to setup a meeting anywhere that was convenient or at hand. The only requirement that the environment needs to provide is for a plane to be able to be detected, which in the worst-case scenario can be the floor. Any detected plane can be then modified to the desired shape and be positioned in the space as a digital representation of the work area for the group, either matching a current table or just providing a space floating in the air. Other technical requirements must be taken into consideration when detecting a plane, but they are more circumstantial. For instance, good illumination and surfaces with a good contrast like colour, a pattern or an irregular surface are easier to detect than simple, monochromatic ones. In the end, a compromise was found between a quick setup of the *workspace* and giving the user the ability to adapt it to the needs of the session.

For the configuration process, the host can see the iterative recognition of any horizontal plane in the space and select one that suits the needs of the session. The host can also transform the selected plane by moving, rotating and scaling it until it fits into the desired shape and position, but that it is not a requirement for the process to continue. Figure 5.24 shows the host view for the plane detection stage and the fine-tuning options.

With this, the *digital room* configuration ends as well as the active responsibilities of the host, and the group can start the work session.



Figure 5.24: Iterative Process for the Plane Detection (left) and Workspace Configuration (right)

The User Anchor

With the main elements of the *digital room* represented, it was also important to create that same element of visual representation in the digital space for each of the users in a session. For this there were two possible approaches:

- Recognising the human face or figure and associate information of the participant to that detected feature.
- Add a digital avatar to the Room that represents each participant.

There are important technological differences between these two options. For instance, face recognition is a common tool offered by most AR frameworks available but not at all categories of implementations in different devices (ARCore, 2025), which could exclude potential hardware to be compatible with *WorkshopAR*. Incompatible hardware is not a surprising issue in this context. Any technological product needs to consider the hardware ecosystem available in the market, but it was surprising to find how inconsistent the compatibility of tools was between different brands and different categories within one brand. Elements like how new a device was, if it was a high-end or a low-end brand or the type of cameras available for the device had little relation to the presence of different AR features.

Another consideration regarding the face recognition option is data handling. There is almost no issue for simple face recognition, that is, recognising that a human face is present. Limitations and issues start to arise when more complex functionalities are needed. Recognising and following a unique face, which would be the functionality in this scenario,

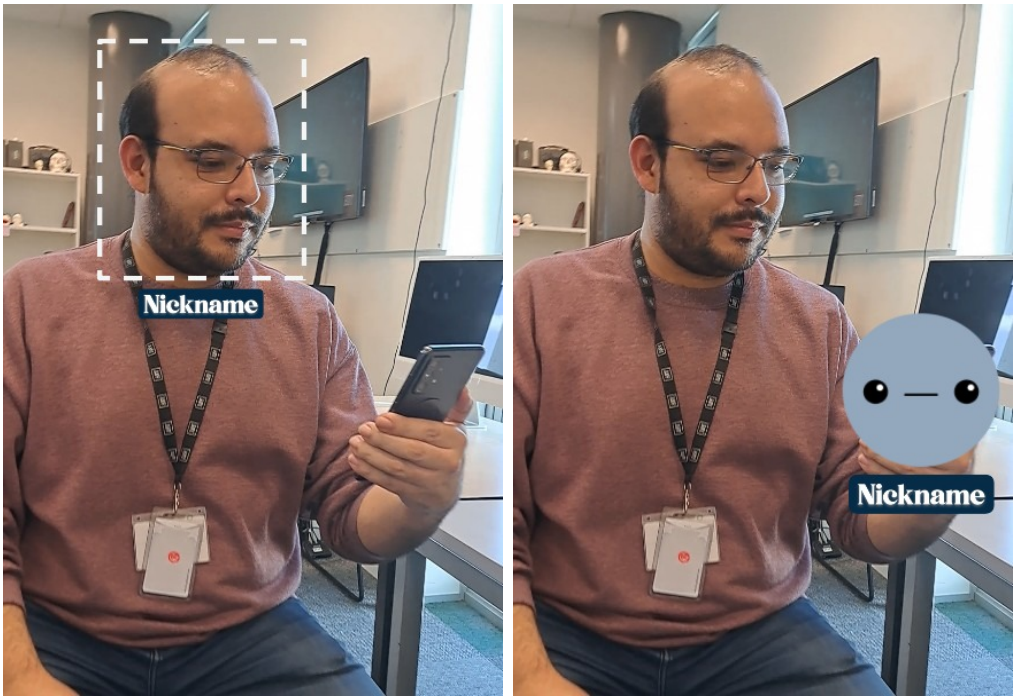


Figure 5.25: Face Recognition (left) vs Digital Avatar (right)

requires collecting and storing a significant amount of identifiable data for each test subject, which can quickly become impractical and an unnecessary ethical consideration.

This decision also became relevant thanks to the observed behaviour of test users during the AR gestures research. Some users, those less familiar with AR technologies, had the expectation for the interface to behave in a more natural, complex way. The way the users are represented in the tool could also be part of those expectations, and for the user recognition to work as a seamless representation of everyone.

Just to pinpoint this possible behaviour and gather more grounded evidence of how the users would react to the different implementation possibilities, a small-scale test was designed that showed a sample of test users a render of the two possible representations of participants in the AR room, as can be seen in Figure 5.25. The subjects had to respond which option they considered the best implementation in terms of how they think the software should work and which option could offer a better interaction with the other users. The test offered a similar objective as the AR gestures research but in a different context and with other type of interactions in mind, but with the same core ideas of naturality and expectations for the technology.

Despite the small sample size, results nicely aligned with previous observations. Some people found that the face ID option was more in line with how AR should work, or how it seemed to work in adds and media representations of the technology. The avatar option received a surprising attention. Despite being described as a more convenient and realistic implementation, like with the menu in the AR gestures data sample, the avatar option was found as engaging, and as a *cute* option that promoted interaction. People wanted to interact with the avatar. These results highlighted the importance of the social aspect of any multiuser experience.

More technical aspects of the implementation shifted the final decision to a variation of the avatar option. The ability to uniquely identify each of the participants in a room consistently was one of the most complex challenges that had to be solved for a face recognition implementation. The development effort for that sole functionality put it out of the scope of the research by not providing critical information for the research questions. Additionally, it would have required sensible data of the users during the data gathering process, unnecessarily complicating the scope of the observations.

The final solution opted for a simplified avatar approach that followed the position and orientation of each participant's device rather than the detected position of the user. This decision offered a group of advantages:

- It was easier and faster to implement.
- Following the status of the device did not require to constantly have the space and the other participants on frame.
- It offered a more stable and consistent visualisation.
- It drew attention to the device, which became an important part of the discussion about how to use smartphones properly in these types of collaborative activities.

The representation itself was simple and straightforward, conveying functionality first but communicating the idea of possible customisation that could be done with a commercial implementation of the functionality. Each participant was represented with a chosen colour for the avatar and showed the other participants a nameplate with the user's selected name for the session and a visual construct representing the gaze of the avatar, linked to the orientation of the camera in the device. The avatar also worked as the interaction point for other participants to see more information, the status of the user and to control how much of the visualisation to be active at a given time, if it was found to distracting. Figure 5.26 shows an example of all these visual elements.

Positioning Play Models

This implementation was a test of the general functionality for positioning the play models in the *digital room*, to test the network backend for the interactions and to receive early feedback and ideas around this functionality from the users.

The intended step-by-step process for this functionality would be as follows, from the point of view of a client user:

1. Connect to a *digital room*.
2. Wait for the *workspace* to be configured.
3. Select a play model to add.
4. Position the play model in the *workspace*.
5. Update the play model for every participant.

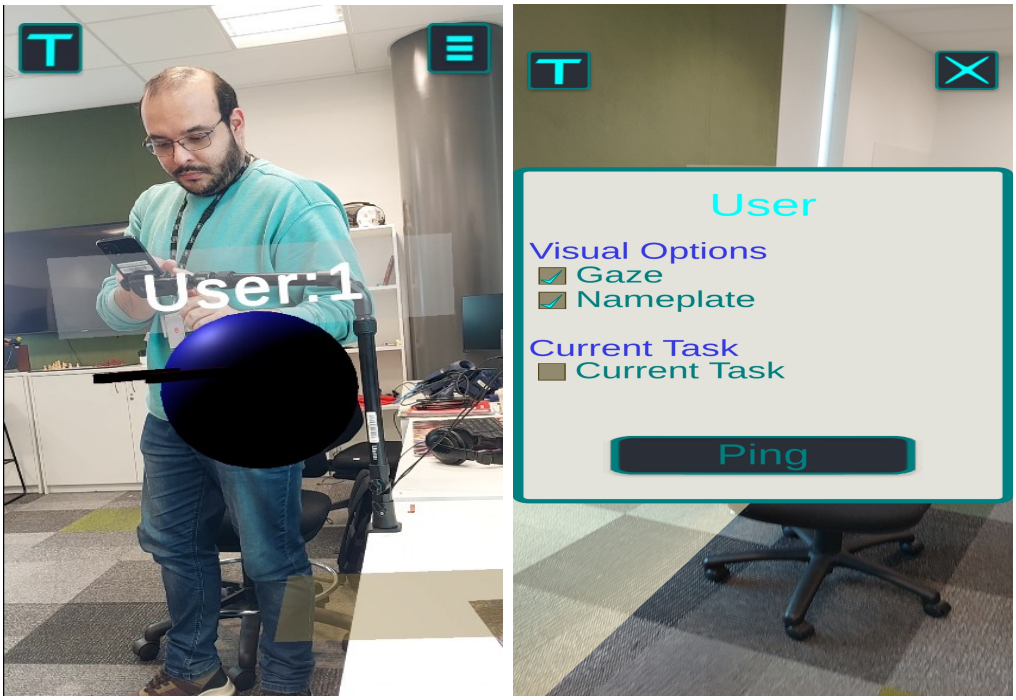


Figure 5.26: Visuals for the User Anchor Object in the Digital Room (left) and the Information Interface for a Participant (right).

Each model is positioned in the room in relation to the *workspace* and will move and reposition if the *workspace* moves. Section 5.2.1 explained that this behaviour of the *workspace* helps the participants to focus on a specific area of the *digital room* as the main interaction and visualisation space, avoiding confusion, lost assets and excessive clutter. The design of the *workspace* also helps in the interaction with play models:

- It limits the space where a model can be positioned, making the process faster and less prone to errors.
- It allows the use of more precise tools for positioning in the augmented space, such as the AR Raycast, to improve the precision and visualisation of the process.
- It can be easily expanded to create more complex interactions in future developments.

When adding a new model to the scene the user needs to point the camera at the position where the model should appear in the *workspace*. A previsualisation of the model during the positioning helps the user to be more accurate. Figure 5.27 shows these elements of the positioning process.

Since no interaction with the model has been implemented yet, most of the development only concerns the backend that supports the process, which can be summarised as:

- Each client has ownership of the models they create.
- The status of each model is managed by the owner (the client) and coordinated through the network with the other users.

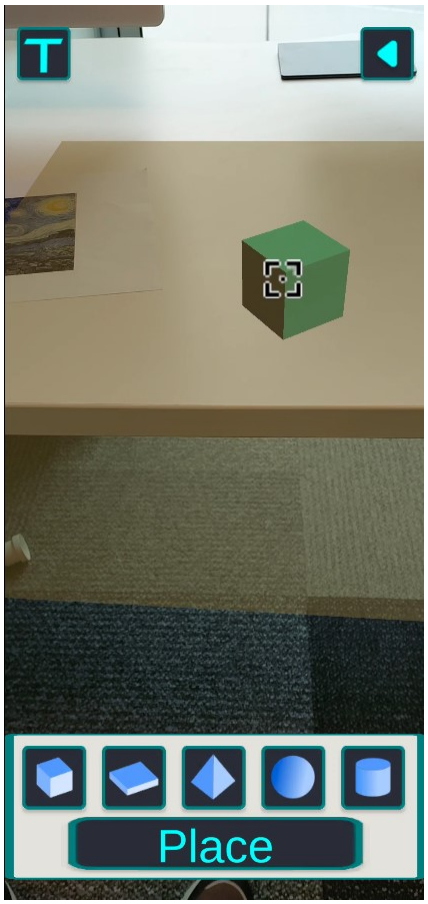


Figure 5.27: Play Model Positioning

- The responsibility of the host regarding the play models is completely on the backend of the application and transparent to the user.

This summarises the major implementations achieved during the first iteration of development, which resulted in the creation of the base procedure to initialise a shared room, the implementation of the major responsibilities of the host client and the configuration tools for the shared space. Good progress was also achieved in the three major visualisation and interaction elements for the participant: the room anchor , the *workspace* and the user anchor.

5.2.2 Analysis of the First Iteration

The full protocol followed during the observation sessions with the students will be discussed in Chapter 6. For this section, it is enough to consider that users, either students during classroom time or participants in unstructured test, where presented with incremental aspects of *WorkshopAR* and prompted to interact with specific tasks during the session to observe and receive feedback from that particular usage. Observations and feedback were recorded and analysed through the whole development of *WorkshopAR*.

In general, it was possible to consider the configuration process of the *digital room* as a success. The participants found the task clear and the controls easy or at least sufficient to accomplish the explained goals. The most prevalent feedback was related to the visual clarity of several of the UI elements present, especially with the controls for the fine tuning of the workspace. It was an expected issue considering that a proper UI design was not the focus of the iteration. It did offer several points to work upon when conducting the final UI implementation: Clear indication of what elements of the digital model are going to change when interacting with it (position, elevation, scale), the ability to quickly correct errors, reverse unintended actions, and verify changes before committing to them.

The most important highlight was observed consistently when positioning the model in the *workspace*. Users had to physically move the device to adjust the position of the model, since it was linked to the centre point of view of the camera. When executing this in a small *workspace* it presented no problem, but it was observed that when the user configured a bigger *workspace*, one big enough to not completely fit on the display, the user had to move around the physical space, often standing up and advancing a couple of steps in the space to be able to position the model. This presented itself more often when the user had a big table or desk in the physical room where the testing was taking place, which compelled the user to adjust the workspace to fit the table although they were not prompted to do it so.

More than an error, this situation generated an undesired behaviour. The need to stand up and move around the room, although not completely unfeasible, was seen as too disruptive. Some users mentioned the situation as a positive, forcing the participant to be more active during the meeting, but it was also perceived as unnecessary if there were proper tools to achieve the same result in an easier way. It was clear that the process had to be refined to offer more control to the users during the positioning process and all other interactions that could use the same system in the future implementation. Table 5.2 shows a summary of the major themes extracted from the observation of six users recorded across four different sessions during the first iteration.

Table 5.2: Main Themes Identified in Observations During the First Iteration of Development

User ID	Comment	Themes
1	Is easier to wait for the bigger one (plane) to appear and pick it	Plane Detection, Process
	The planes that appear at the beginning and the final one that I pick should be the same colour	UI, Plane Detection
	I don't want to tap it (the button) all the way to the other side; I will leave it (the workspace) here	Plane Controls
	I was expecting it (the play model) to move when I slide in the screen	Model Controls
2	The arrow (on the button) needs to be bigger; I have fat fingers	UI, Room Configuration
	The button needs to change colour or something like that, I am not sure if I pressed it or not	UI, Plane Controls
	Maybe if the cube does not disappear on the border?... Keep always the cube on, I thought I had lost it	Model Controls, UI
3	Where is the colour I picked at the beginning?	UI
	Probably I have to lean a little too much? The pane is too little; can I make it again?	Model Controls, Plane Controls, Process

Continued on next page

Table 5.2: Main Themes Identified in Observations During the First Iteration of Development (Continued)

4	Cool, how big can I make the table (workspace)?	Plane Controls
	It would be cool to stack them (the cube models)	Model Control, Process
	I'll have to go there and get the cube; I made the table too big	Model Control
	The table sometimes moves. Is not too much but I can notice it	Drift Problems
5	I will get tired of holding the camera in this position	Process, Model Controls
	I feel like the plane moves in the opposite direction that I want it to move, but is only sometimes	Plane Controls, Drift Problems
	I confirmed the plane by accident (...) can I edit it again?	Plane Controls
6	The buttons need to be more descriptive, not only the name of the axis, not everyone knows that	UI
	If only one person has to create the plane, it is very nice, it is quick	Process
	The plane moves a lot (...) Well, it tries to readjust if I move the camera away	Drift Problems

Similar results were obtained with the first round of interviews to students of the Industry Project course. A more detailed report of the activities done during the first weeks of observations can be found in Section 6.3. To summarise the data obtained and focus the analysis to the evaluation of the first iteration of development, two main objectives guided the initial approach with the students:

- Introduce *WorkshopAR* to the students and discuss how it could be used as part of the activities of the course.
- Identify preliminary feedback from the students about the implementation of *WorkshopAR*, the proposed process to use it as part of their project and the results expected from them while working with the tool.

From these informal interviews with the students, it was possible to identify that the initial main concern and task for each student was to meet and get familiarised with their other teammates, since the groups were organised at random. They perceived *WorkshopAR* as a useful tool with this task, as it could display information about people they have not yet met and could work as an interesting medium to start a conversation with other people, as some form of *icebreaker*.

On the other hand, the process of organising all the communication mediums needed for the group to work properly was already a major concern for most students, who found that adding another tool to the repertoire of outlets they had to manage could rapidly become a source of stress rather than help.

A third group of students where a little behind the others in terms of organising their teams and were just understanding the amount of groupwork that the course required every week. These students just started to talk about the situation and how to deal with it. In this scenario, introducing the idea of *WorkshopAR* prompted a discussion about how to organise the group around the collaboration requirements of the classroom, although the tool itself was a little tangential in that discussion.

A final set of comments came from quick interactions of the students with the visual elements of the *digital room*. The students found that the idea of the *workspace* was very useful. Comments highlighted that it could help with organisation, to set up a quick meeting anywhere or could help the group to focus on the work. Some students also mentioned that, if the *workspace* could be personalised, it would be an ideal tool to create a sense of identity for the group by offering a unique visualisation for every team.

The user anchor also received some feedback, which echoed the information found on the test described in section 5.2.1. Some users found it interesting and a good tool to have at hand during that first meeting activity they were experiencing. Others were concerned that the anchor could be very distracting and get in the way of other visuals. The main complaint was that it was too charged with information, and that it would be useful to have the option to hide it or to make it smaller and less intrusive.

Table 5.3 shows a summary of the most relevant ideas discussed around the topic of the user anchor during 8 different observations across two classroom session. Based on that data, it was considered important to work on the following adjustments before starting the second iteration of development:

- A better interaction model for the position and movement of play models, one that was not solely reliant on the movement of the device, since the users found it unprecise and frustrating, and that required too much physical movement for an activity that should have been simpler.

- Adding configuration options to hide the most distracting elements of the user anchor, like the gaze and the nameplate.

Table 5.3: Main Themes Related to the User Anchor in Observations During the First Iteration of Development

User ID	Comment	Themes
1	I know nobody here, so it would be useful to have their names at hand until I learn them	First contact, User Anchor
	I could play for hours with the avatar if it has many dress-up options or things like that	User Anchor, Distraction
	It is a good way to use the phone to work and not to procrastinate	Phone Usage, Positive Expectation
	I would prefer to discuss things with my teammates face-to-face rather than through the phone	Digital Communication
	I prefer face-to-face communication; there are always problems with things like WhatsApp and Teams	Digital Communication, Negative Concern, Team Management
	I am worried that this project will need a lot of coordination from us, there are a lot of things to coordinate	Negative Concern, Team Management

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Table 5.3: Main Themes Related to the User Anchor in Observations During the First Iteration of Development (Continued)

2	I always have problems with people not making contact, or appearing in the last possible minute	Team Management, Negative Concern
	I would prefer to work on my own than having to come to class every day. It is faster	Team Management
	I know I can get very distracted with my phone	Phone Usage, Negative Concern
	The models can be a good idea to involve everyone in the conversation, even those who normally not speak	Team Management, Positive Expectation
	I try to keep a visual diary of my work; the app can help me with that	Digital Work, Positive Expectation
	(. . .) I already have to coordinate my files in a bunch of places; this would be one more	Digital Work, Multiple tools, Negative Concern
3	Can be useful to work, but I bet a lot of people will just not come to class	Team Management, Negative Concern
	I would start playing with the models, I know I can get distracted easy	Digital Work, Negative Concern
	I could get some help organising my work, I would probably hate it (..) but still use it because I know it is helping	Digital Work, Negative Concern
4	Can help with organising ideas or moving a conversation	Team Management, Work Management, First Encounter
	I try to disconnect when I need concentration, if the app is in a phone, I know I can have problems with it	Digital Work, Negative Concern

Continued on next page

Table 5.3: Main Themes Related to the User Anchor in Observations During the First Iteration of Development (Continued)

5	It can help with communication a lot, especially if it is hard for you to talk with others or to organise your ideas	Team Management, Positive Expectation, Digital Communication
	The avatars are a little scary. I think they could be distracting, moving around while you work	User Anchor, Distraction
	They (the user anchor) can help. If this could work online, is like having something that represents the people that is not here.	User Anchor, Positive Expectation
6	The avatars are nice, giving a little personality to the activity	User Anchor, Work Management, Positive Expectation
	Can you also decorate the table or the room? Every team can have a different layout	Workspace, Work Management, Positive Expectation
	You have to balance the game features and the work features, or is just distracting	Phone Usage, Negative Concern
	After a while I suppose you would just do your work and ignore the app	Negative Concern
7	I will mostly work from home, but it could be used to have a form of view of what the others are doing	Work Management, Team Management
	It can also be used for planning, like a presentation or a document that has parts from everyone	Work Management

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Table 5.3: Main Themes Related to the User Anchor in Observations During the First Iteration of Development (Continued)

	I can use it as a repository for ideas, or a portfolio. It would be ideal if it could connect to things like drive or Miro	Work Management, Digital Work, Multiple Tools
8	Can anyone enter to the room? It would be nice to be able to make your room truly yours, and other people know when they are in your space	Workspace, Work Management, Positive Expectation
	I work with several screens at the same time; I can see this app being another tab I have to manage	Digital Work, Negative Concern

5.2.3 Second Development Iteration

The second iteration of development took place for approximately six months and focused on gradually testing the remaining fatures of *WorkshopAR* related to the playing models, annotations and communication emotes. The majority of the observations for the case study took place duing this period, observing four different groups of 18 students thorughout four classroom sessions. As before, this section will focus on the technical analysis of the features tested.

Pointing

One of the use cases that was not properly implemented during the first iteration was the functionality to point at different elements in the Room, specifically play models, other participants, and points in the physical space. This implementation lost priority due to some of the observations gathered during the first testing phase, as well due to the technical issues found for its implementation.

Although pointing could be useful to clarify an intention and to avoid ambiguity in cluttered spaces, the functionality was seen as secondary to other options, since the participants found it easier and preferable to rely on direct communication with their peers, rather than defaulting to communication through their devices.

Another issue found was related with the number of gestures being proposed for different actions and the need to remember them to execute the desired functionality. Users consistently proposed or remarked that a better approach was to link a single interaction, like a touch or an air tap, to open a menu or a list of contextual possibilities. This also mirrors the current UI design tendencies in similar applications and headsets (see ARCore (2025) and Horizon (2025) for example).

The implication of the data found was that it was more important to offer simple and quick interactions rather than using elaborate gestures. Figure 5.28 shows examples of the



Figure 5.28: Selection Menu for Participants (left) and Play Models (right)

contextual menus created which were linked to single interactions taps to the different digital objects in the room. This implementation was identical for pointing objects and participants.

Initially, the visual design for the functionality focused on the single objective of pointing to an object in the digital space. The idea behind this decision was that students would prefer a subtle and simple visual feedback that minimised distractions and possible disruptions to their work. Curiously, upon testing the functionality in the classroom, the students found that the idea of pointing or calling attention to an object or participant was not as useful as initially though, or more specifically, was the least useful idea that was coming to mind. Students started to propose a wider selection of option for visual markers that could be used in different scenarios, not just pointing. Students proposed scenarios like approving and idea, giving feedback in a conversation, asking for the removal of an element or helping to convey a decision taken.

Figure 5.29 shows some of the options added to the *ping* command, that was now treated as an option to add a visual reaction linked to an object or a participant, not only the action of pointing. The idea was to offer options to highlight an object, confirm and deny something, all based on the recommendations given by students for different types of interactions and situations.

Pointing at an object in the physical space presented a different challenge. The main issue was related to not having a digital anchor that could reliably hold the pointing visualisation, like the user anchor or the play models themselves. For a physical object, the pointer had to be positioned in relation to the shared origin of the *digital room* and the perceived position of the object by the participant doing the pointing. Two options were proposed to achieve this behaviour within the architecture of *WorkshopAR*:

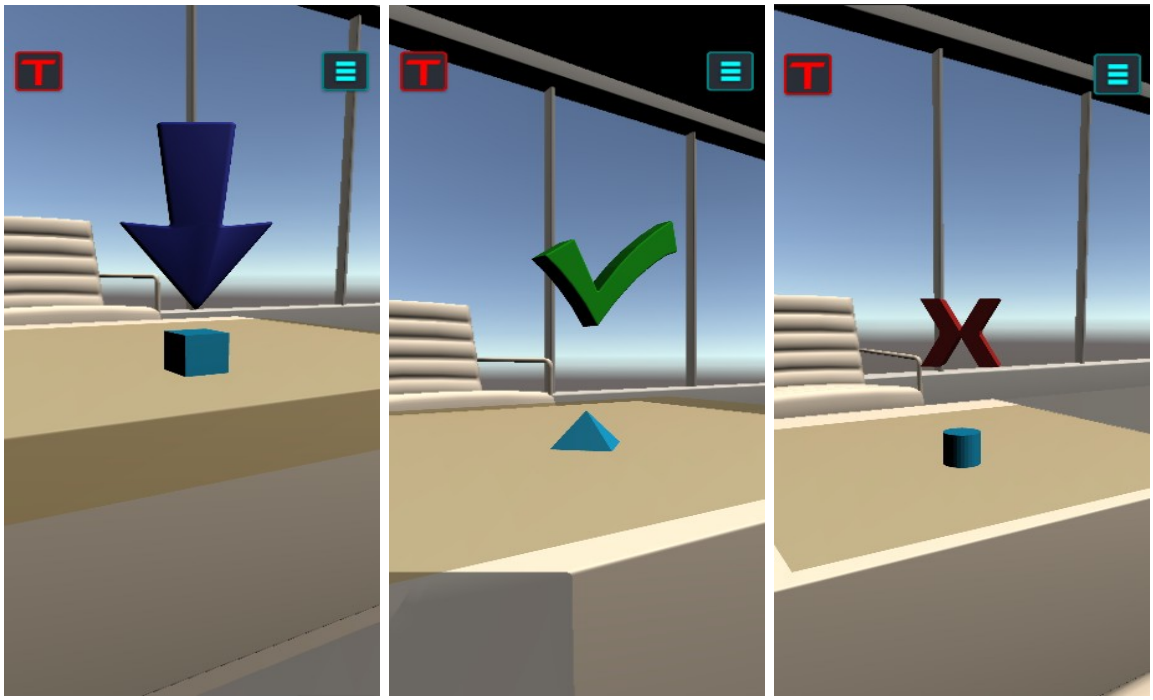


Figure 5.29: Different Options Added to the Pointing Interaction

- Expand the plane detection to identify as many surfaces in the physical environment as possible, creating a set of invisible anchors that could be used to hold the pointer as close as possible to the point in real space.
- Use the AR Raycast to estimate a distance to the point in space where the visualisation should be added, based on the visual feedback of the participant's camera.

Since the students preferred the tools to point at the play models rather than to objects in the real space, it was possible to experiment a little with both approaches without fully committing to a definitive implementation to show to the students. Figure 5.30 shows examples of the mock-ups implemented for both scenarios.

Expanding the plane detection offered the most precision at the cost of configuration time. It would be possible to ask the host to spend more time scanning more elements of the environment to create this *holders* which could be turned on and off when positioning a pointer in space (or other digital objects, like annotations). The plane detection could also be turned on for every client connecting to the *digital room*, distributing the responsibility among all participants and helping to refine the detection of features in the room using shared information across the network (Braud et al., 2017; Pereira et al., 2021). In either case, the implementations add a more complex layer of configuration to the digital room, and makes the existence of the *workspace* unnecessary, which was though as a simplification of the process to begin with. This idea can be refined and expanded in future work, focusing on the idea of a shared scan of the environment to off-load configuration responsibilities and time.

The Raycast option offered a simpler development as well as a simple interaction process for the users. The problem with this approach is imprecision, mainly because the local

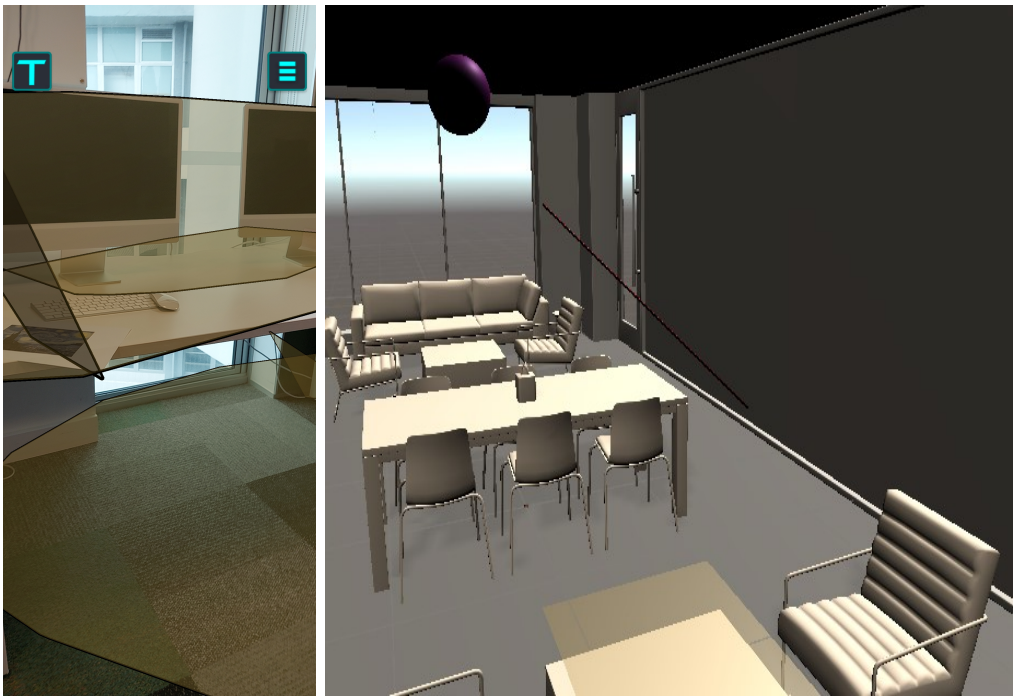


Figure 5.30: General Plane Detection (left) and Raycast Estimation (right) Tools

position of each device in the shared room is not completely synchronised. Not only is each visualisation based on the position of the target image, which is impossible to completely reproduce in every scan, but the colocalisation process also always creates a noticeable drift of the visualisation over time, especially if a direct visual to the target image is lost for too long. The drifting and the differences in points of view causes that every digital object looks *off place*.

The participants came up with an interesting solution for this scenario using the tools at their disposal. They resolved to point at a thing, digital or physical, using the gaze of the user anchor. Since the anchor follows the position and orientation of the device, it was easy for the users to position the anchor in relation to what they wanted to point at. Other participants would look at the user anchor through their own devices pointing with the gaze at the object in question. To accommodate this behaviour, a simple tool was developed to extend the gaze of the anchor as shown in Figure 5.31 to use it as a digital telescopic pointer. In coordination with the ping animations added, it was possible for the students to point at different entities in the room and even convey an array of meanings that were not considered in the initial design.

Interacting with Play Models

The development of this functionality focused on three main objectives supported by the comments and ideas gathered from students and other tests subjects:

- A varied set of shapes that could be adapted to diverse scenarios and ideas.
- The ability to stack and snap models together to create more complex structures.

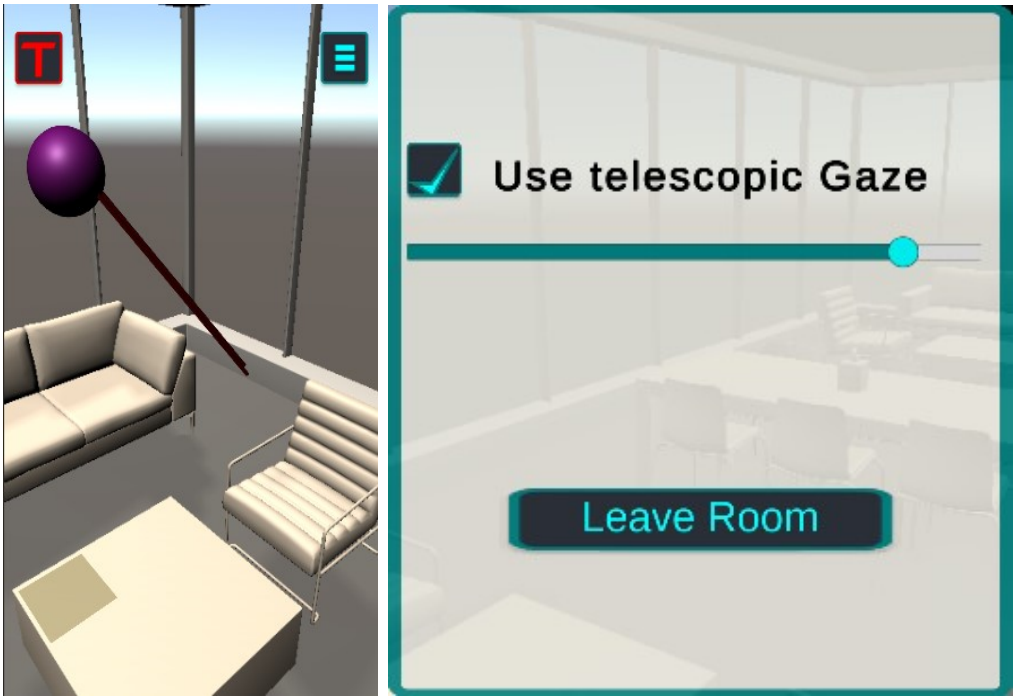


Figure 5.31: Visuals (left) and Controls (right) for the Telescopic Gaze Used for Pointing

- A quick and easy interaction using the touch screen or simple movements of the device.

Figure 5.32 shows the simple set of basic models that was added to offer the students different possibilities to build their ideas. The possibility of adding to *WorkshopAR* a visualisation of any model build in externals tools was discussed with the students. Although some of them expressed interest in the possibility of interacting with such a functionality, there were also those against the idea, or more specifically, against the need of using such a tool. For instance, the diversity of profiles in the backgrounds of the students conforming each group meant that only one or two team members had a background in architectural or construction engineering, and sometimes there were none. Therefore, not many students were confident or interested in directly manipulating or interacting with architectural models, preferring more high-level discussions or using tools they felt more familiar with. To facilitate the overall development of the tools and focusing on as many student profiles as possible, it was decided that the implementation using the base play models was enough.

The interaction itself with the models evolved from the tools implemented for the configuration of the *workspace*, as well as incorporating the feedback obtained around that functionality. In this new version of the controls, the movement of each model was linked to a point in the centre of the camera and would follow any movement detected in the device. An additional control point was added to the touch screen, where a widget would show the user what interactions where possible when dragging the cursor in a particular direction. The cursor would also act as the centre point from which the *Raycast Manager* would work, allowing for the movement of the camera to keep working as a mean to move the play models. This setup provided several ways for the user to fine tune their positioning and selection. These same controls were extended to the *workspace* configuration, where the issues were

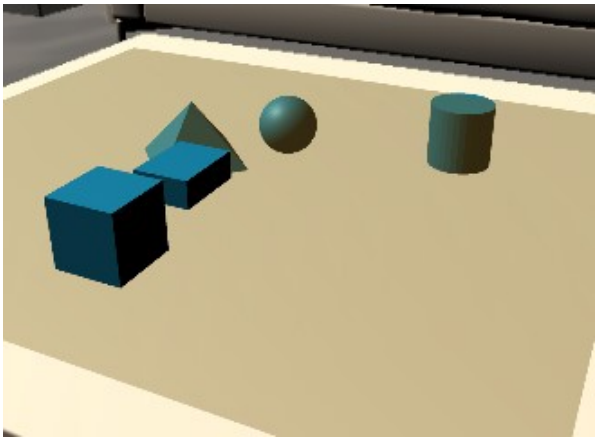


Figure 5.32: Available Play Models

initially identified. Figure 5.33 shows examples of the visual elements for these controls.

Parallel to the interaction design for each user to move and position the play models, it was necessary to design and implement a proper protocol to control several participants interacting with a single model over the network. The architectural design established the network authority for each play model to the client that initially spawned the model in the *digital room*. The final implementation simply expanded that design to coordinate the transfer of ownership whenever some other participant wished to interact with a play model. Since the prototype of *WorkshopAR* shown to the students did not contemplate any form of persistence of the session, keeping track of the ownership of models was unnecessary.

The whole process is transparent to the users, and by design, the participants have no awareness of the ownership they may or may not have of a model, since the idea is that the *workspace* should be considered as a public zone for shared resources. Nonetheless, it was important to convey the idea that someone else is interacting with a given model, enforcing an external protocol to organise the interactions between participants and relying on physical communication and external teamwork. Figure 5.34 shows examples of the visual elements that enforce the organised interaction with the play models.

Finally, it can be interesting to mention at this point the discarded functionality of the personal workspace. Section 5.1.1 explains the logic behind this concept. Through the analysis of the literature, the idea of distinguishing between a shared and a personal space surfaced as a concept that needed to be conveyed graphically and through the interaction design. From the data gathered, it was determined that the users did not find such a distinction useful or crucial. The possibility of having a private interaction during the shared work session was seen as troublesome instead.

Annotations

The idea behind annotations was to offer the students the ability to record information in written text and to possibly *attach* that knowledge or ideas to elements in the physical space, creating relationships between concepts, conveying new meaning or using the space as another resource to work with.

In contrast to the play models, the annotations are not limited to the *workspace*, and



Figure 5.33: Control Tools for the Position (left) and Rotation (centre) of the Workspace as Aell as the Positioning of the Play Models (right)



Figure 5.34: Visual Elements that Enforce the Shared Interaction Protocol

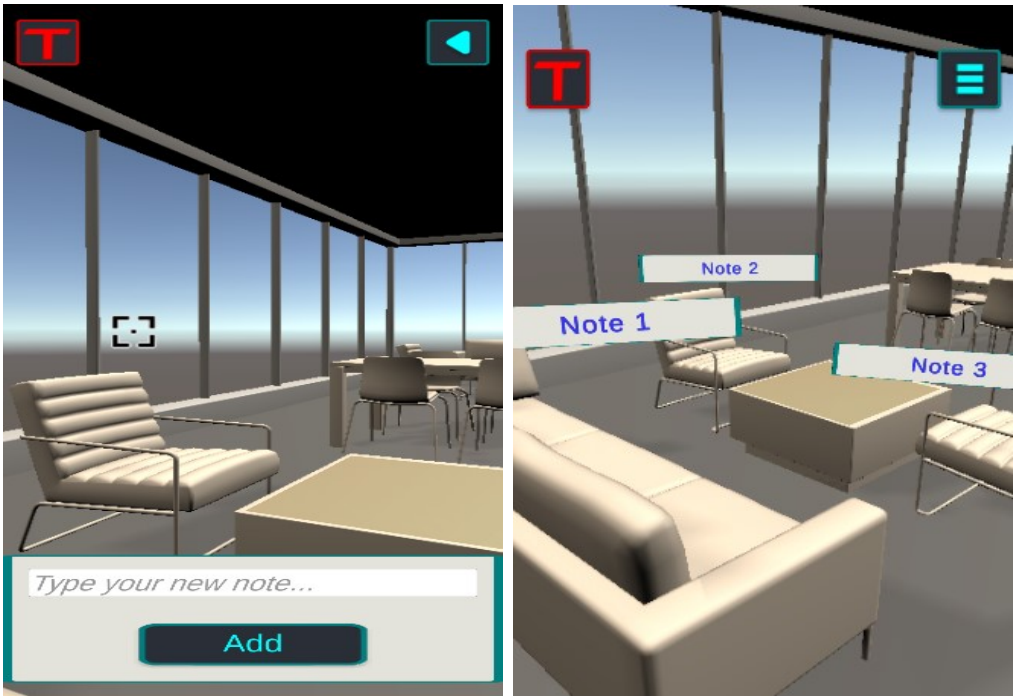


Figure 5.35: Controls for Adding (left) and Managing (right) Annotations

can be placed freely anywhere in the room, which necessitated a solution similar to that of pointing objects in the space to position the annotation, taking into account all the challenges related to low accuracy and changes in points of view discussed in Section 5.2.3.

During the design analysis and in data gathered from the students, the concern of creating too much visual clutter in the *digital room*, either by accident or maliciously, was mentioned. Two tools were constructed with the purpose of giving the students some control over the situation, by allowing to hide some or all the annotations and by allowing each user to disable the visual aesthetics created for the digital objects associated to the annotations. Figure 5.35 shows examples of the localisation and control mechanics created for this functionality. In the end, as with other tools like the pointing mechanics, it is possible to create a hindrance or a distraction if misused. Some considerations were taken to allow the users to manage what is been shown in the local device, but it is important to consider that no amount of control is infallible, and proper team management and digital etiquette is always the best policy (Galimullina et al., 2022; Ribble et al., 2004).

For the implementation shown to the students, only text annotation was considered. Although images that could be used as annotations were compatible with the current implementation, there was not an easy solution to offer the students the ability to create or add meaningful images to the system, compared to how simple it was to create meaningful text. A solution that was prototyped but not tested due to time constraints was to use the local storage and camera utilities of the device to act as a source of images. The emote functionality was also expanded to the annotation feature as will be shown in the next section.

Debates and Emotes

The final functionality implemented that piqued the interest of the users as identified during the test phase was the tool to manage discussions and voting processes. It was also the functionality that changed the most from the design phase in response to the comments and ideas collected from the users.

In the original design, an interface was presented to the students with information about the vote question or premise and the possible options to select. The structure and organisation of the team around the discussion was left to the students to execute with the amount of structure they wished to implement. This proposal prompted two set of opposing opinions among the students. Some users questioned the necessity to interact at all with the application to organise the debate, highlighting how disruptive the idea sounded for the communication between participants. In contrasts, others found the idea of interacting with visuals that conveyed more information about the activity as useful and a way to *spice* the conversation and help make the activity more interesting. It was clear that the mechanic was divisive at best, so it was important to find a common middle ground between the two views, reinforcing the positive aspects of the activity while mitigating the negative observations.

Three elements were identified as the core of the experience and that could provide the most advantages in any scenario or usage of the tool:

- Signal to the participants that an activity involving the whole group was necessary.
- Quickly check information about the discussion topic and the possible answers or options, if any.
- Quickly check the answers provided or the positions taken by each participant.

Alternatively, the most concerning aspects of the use case related to forcing the participants to interact with a digital interface when a quick face-to-face discussion was possible and probably creating a hindrance to communication by limiting answers to what was configured in the application. Forcing a strict structure to the debate process also concerned some users that could see such process as something that would make any activity with the group take longer or be prone to mistakes and delays.

The final implementation offered the possibility to approach the debate process with two degrees of structure. The loosest version of the activity would act only as a general call to all participants in the *digital room* to pay attention to the team member that initiated the activity. The only UI element present would be a notification that a debate was in progress and who started it. Elements like the subject of debate, possible answers and the voting process itself was the group's responsibility and outside the flow of the application.

The second level of structure required configuration of a topic and voting options. The UI then would show this information to each participant, as shown in Figure 5.36. More configuration points for the structure of the activity were considered, like forcing participants to vote and allowing for a flow of question-response activity to take place, but only the first two levels were implemented and shown to the students, while some other options were discussed.

Interaction with the UI, especially during the voting process, was completely changed to avoid the major critique of forcing interaction with the device for an activity meant for

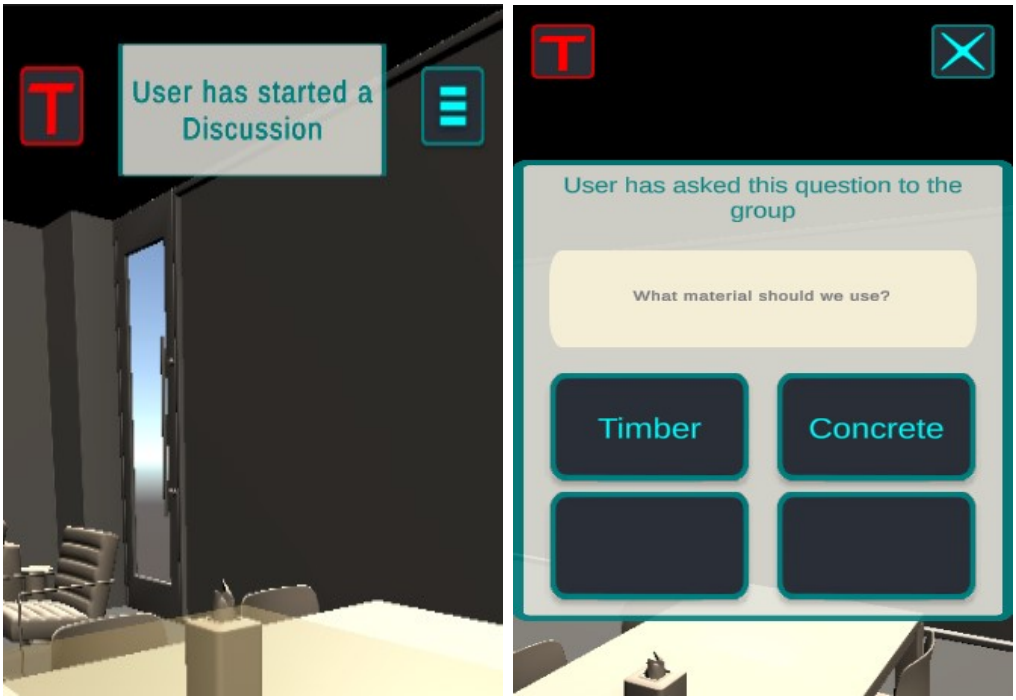


Figure 5.36: Discussion Tool Interface for the First (left) and Second (right) Level of Structure

face-to-face communication. Combining the ideas acquired from different users, a system of emotes was implemented linked to the visualisation of the user anchor, which was closer to the position of the device and to the person controlling it. The emotes would show a visual from a selection implemented in the application that could represent several meanings depending on the context. The emotes implemented represented simple affirmations or negatives, as well as set of possible answers or postures using the letters A, B, C, D and a set of colours. Figure 5.37 shows examples of some of the emotes implemented.

The solution was not perfect but emphasised the priorities and the development goals of *WorkshopAR*, using visuals to augment the collaborative process without undermining the value and need of communication. It is also the most prominent example of the user-centred design of the tool, and of the importance of incorporating the final user early in the design stage, to align the needs of the users with the objectives of the development and to understand the ramifications of a decision in the learning background where the tool is going to be implemented.

5.2.4 Analysis of the Second Iteration

The final evaluation process of *WorkshopAR* tried to focus primarily on the new functionalities shown to the students but also was intended as a post-mortem of the development process as a whole and its impact on the overall learning intervention and research goals.

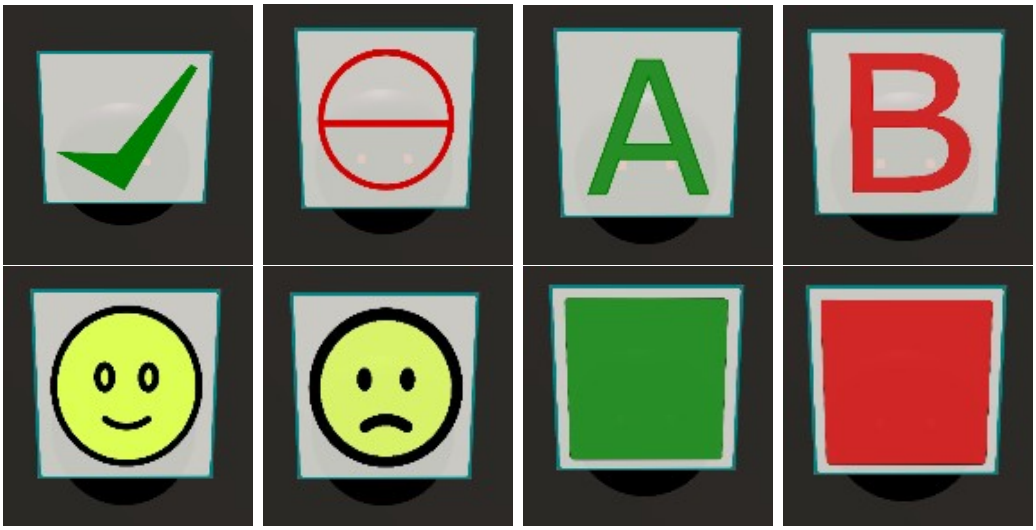


Figure 5.37: Emotes Created for the Discussion Tool

Implementation and Analysis of the Use Cases

The implementation of the second iteration focused on fleshing out the use cases identified as most relevant during the design phase. In general, users orbited the most around the interactions with the play models and the emote features present in the debate tool.

The pointing and debate feature where the ones that changed the most based on feedback and input form the users, incorporating interactions and visuals proposed by the students themselves as a direct result of the interaction with the scenarios explored during the observation sessions.

The feedback loop implemented during both instances of testing proved invaluable to understand the real context in which the application was being used, the problems found by the users naturally interacting with the software and the workarounds they used. It created opportunities to analyse the behaviours promoted by the tool, to take notes of positive or interesting developments to work upon and to identify instances in which was necessary a course correction.

An important amount of development time was invested on creating a consistent positioning of digital objects in the *digital room*, with mixed results obtained. A combination of the image tracking colocalisation technique and the natural drift present in AR visualisations caused several issues with the overall visualisation in each user's device, which often made. the users re-scan the target image or even forced them to exit and re-enter the *digital room* to reset the visualisation.

The problems observed were not breaking the experience and were completely expected, hence the tools to reset the whole visualisation. Nonetheless, these issues represented a common focus of malcontent and an important aspect of the project to work upon in future research, adapting different techniques to work with drifting ad positioning issues such as the ones proposed by Ran et al. (2020). It could be of interest to explore these solutions in a shared scenario, specially one with the characteristics observed in the case study, where the point of view of the users was constantly moving and the application was not in constant

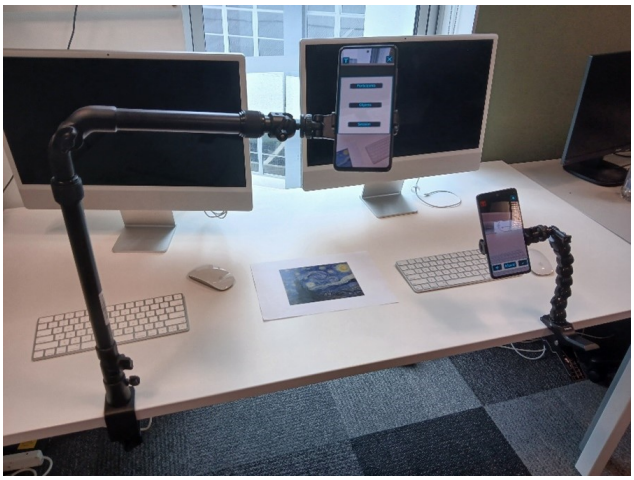


Figure 5.38: Setup with Articulated Arms

focus on the device.

The second biggest tweak of the initial design is strongly related to this situation, since it explains why the application was constantly losing focus on the device. Users needed to concentrate in other aspects of their work not necessarily related to the application, moving to other apps, other devices or simply taking a break from the activity. Several students also mentioned not feeling comfortable constantly being aware of their phones to participate in the *work session*, preferring and finding more productive jumping form their laptops to a direct conversation with ease, without having to set-up *WorkshopAR* all over again.

This was considered as a major behavioural issue, more suited to be accounted for in the learning design, as will be explored in Section 6.6.2. An approach to deal with the situation through the interaction design attempted to give the students the opportunity to keep their devices in a more stable and fixed position using articulated clamp arms, as shown in Figure 5.38. This setup allowed the students to user their devices as a second screen while they were working, with their laptops being the device assigned to production and the smartphone rig as a tool for communication and the centre for the shared experience of the group.

The idea was to find a middle point between a complete free-range use of the device and a more structured and controlled one, but it was still far from perfect. In first instance, it ran against the flexibility goals proposed for the design of the tool since the setup forced the group to have access to tables, chairs or similar surfaces to use as a support for the arms, as well as having access to the arms themselves or structures that could work like the arms. The situation undermined the idea that WorkshopAR could augment any space to help with a *work session*.

Table 5.4 codes the most important comments and observations gathered from the students around the articulated arms arrangement. Positive outlooks highlighted the *professional* look of the setting, which resembled a control centre or a dashboard. Some other students compared it to the setup that some streamers use while creating content, indicating that the setting supports the idea of a social activity.

Negative views on the other hand mentioned how cumbersome the arms could get, restricting freedom of movement and forcing the device to be part of this single activity. More

important, the setting did not fully address the concern of many students that *WorkshopAR* was giving too much emphasis to the phone, giving it a spotlight in the group and facilitating access to it, when the focus should be on the conversation or the work being done by the students.

Table 5.4: Comments About the Articulated Clamp Arms Setup

User ID	**Comment**	**Themes**	**Tone**
1	It feels very excessive, specially the big one, you need a whole table just for the activity	Size, Cumbersome	Negative
	The little one (arm) is more discrete (...) I am thinking of those little stands for the phone, you can take them everywhere (...) They are more flexible (...)	Size, Practicality, Alternative solution	Positive
	I am committing my phone to the arm, I cannot use it for anything else	Practicality, Phone Access	Negative
2	It makes me feel like a tourist with a selfie stick	Cumbersome, Negative Comparison	Negative
	Once it is set up, it looks very professional, like I am doing a stream (...) can be useful for a more complex work that what I plan to do right now.	Practicality, Positive Comparison	Positive

Continued on next page

Table 5.4: Comments About the Articulated Clamp Arms Setup (Continued)

3	It works for keeping the camera pointing at the image (...) but I feel I lost access to my phone, is a weird trade-off.	Phone Access, Practicality	Negative
	I would prefer the small one, if I need to get rid of everything or if the class finished, is less of a problem than the big one, who would carry that?	Cumbersome	Negative
	If you put the effort, the big one can be useful, it is just awkward to use. Maybe if it is always here in the classroom, and you just put your phone in there to work.	Alternative Solution, Lost Flexibility	Positive
	The big one could fit better in an exhibition or a big presentation, with a lot of people checking the AR stuff.	Alternative Solution, Functionality	Positive
4	If I put it here next to the PC now, I feel in a control centre, almost like a hacker. At least it looks interesting.	Positive Comparison	Positive
	Probably not for everything, but I could work using the smaller arm, using the phone like a second screen (...) checking on the AR stuff (...) and if I am talking with someone while working, it could be a possibility.	Practicality, Functionality	Positive

Although slightly obstructed by several technical difficulties, which are common in this type of developments, the final round of implementation can be considered a success. It was not only possible to prototype and test all the use cases proposed, but substantial iterations

over the original design improved and pivoted the original design. The genuine interest of the students provided useful insights thanks to their investment in the process and they were able to perceive value in the inclusion of the tool to their workflow.

Analysis of the Overall Development

The development of *WorkshopAR* was contextualised by the exploratory needs of the research, and the process was always aiming for flexibility and adaptability, as well as framing the whole activity as an exercise in user-centred design, which was identified as a useful process to integrate the software development with the learning design at the core of the research.

Chapter 4 outlined two main objectives specifically concerned with the technological development of *WorkshopAR* (see section 4.1.2). The first goal was to provide a networking framework that allowed the students to configure a shared experience and create a sense of connection to the digital space to be use for the activity. *WorkshopAR* successfully created such an experience in scenarios like the contextualisation that the students gave to the tool, related to the social aspects of their work, and how they adapted what they considered the most relevant functionalities of *WorkshopAR* in a way that worked the most for them.

A first positive highlight is related to the *digital room*. The idea of both creating and joining to the *digital room* established in the students the sense of space needed to work, as well as allowing for a connection between the members of the group sharing the activity and working towards the same purpose.

In contrast, what initially was considered the most appealing elements of the *digital room*: the play models and the annotations, ended up not being as interesting for the students. The users engaged with the functionalities and provided valuable information, but their interest did not go too far from that. One of the main reasons was the nature of the work the students were doing for the course, more related to quick chats with their teammates and with the production of written materials.

Ideas and interactions over the concept of the digital room were plentiful, highlighting elements about the different media that could be added to the room to extend its functionality, the ability to save and recreate the state of the room to reuse it later and even comparing the tool in general with a 3D repository of information generated by the group, like a more tangible version of a shared folder in tools like Dropbox or OneDrive. Other comparison shared mentioned software like Zoom, Discord or Teams. This is important because it shows that the users were understanding the *digital room* as a space for connection, communications and shared resources, part of the intended design. It also highlights the social and collaborative elements at the core of *WorkshopAR*, and the general design goal of *augmented collaboration*.

The technical difficulties encountered during the development of the networking infrastructure also highlighted one of the most contentious aspects in the implementation of AR technologies when put into the conditions that can be found in a classroom. A strong argument can be made, based on the observations gathered and the record of similar results in the literature (see Chapter 2), that one of the major obstacles of educational AR is the lack of stability. The technology tends to fail, its quality depends strongly on the capabilities of the devices at hand and it is easy for the users to find points of friction in the usage of any tool, which immediately affects the flow of the learning experience. Another telling example for this argument is that the most successful implementations of AR found in the literature

were related to medical learning and the chirurgical practice, and were projects characterised by very tailored technology, often build from the ground up to fulfil the specific learning goal at hand.

An important challenge for implementing any technology in the classroom is offsetting all the extra elements injected by the technology (configurations, accessibility, learning curves, points of failure) with the tangible benefits in the fulfilling of the learning goal. In analysing and evaluating the impact of the prototype built, it is possible to propose that the following elements linked to the use of AR offered the most positive influence and promoted desirable or interesting behaviours in the students:

- The opportunity to discuss the level of structure to implement for the interactions in the group and to have visual elements that identify that structure and allows interactions with it.
- To add layers of meaning to different elements and resources of the collaboration, such as the physical space, the resources at hand and the communication process taking place.

These observations create a contrast with the original hypothesis proposed, where the interaction with the digital objects and the use of strong visuals in the augmentation were proposed as the most important drivers of the tool. The evidence shows that the students did not rely much on functionalities like the play models or the annotations but were drawn by most simple and practical features like the emotes and the user anchors. These features were also characterised by offering the capacity for expression and choice.

The second goal proposed for the technical aspect of the research was to create a multi-platform experience that highlighted and enabled flexibility in terms of the hardware needed to implement the experience on the classroom, to offer increased accessibility and to align to a Bring Your Own Device (BYOD) philosophy of Technology Enhanced Learning (TEL).

In terms of development, the tools at disposal in the current market and development environment offer an amazing opportunity to fulfil this objective almost 100%. *WorkshopAR* covers a wide range of mobile devices with a single code base and can cover several more distinct devices with few adaptations.

The interaction design process followed to support the multiplatform objective was also successful, and the user-centred approach proved indispensable to obtain quick feedback and promote a development with constant iteration and adaptability, as mentioned several times previously. An interesting follow-up to this line of research would be to offer flexibility on the interaction design by coordinating the interaction with different types of input devices.

However, the multiplatform design was not without its issues when tested against the real context of the implementation, and it managed to both overshoot and underperform in the eyes of the students. Although compelled for an experience using AR to explore and learn different concepts in their professions, the students expressed a strong reticence to the idea of relying entirely on the technology to complete their academic work. The responses aligned with previous negative observations around the idea of constantly using the phone during the activity in class. The idea of working in the classroom while wearing a headset like the Meta Quest or the HoloLens was out of the question for the same reasons, at least not *with the current bulky technology*, as commented by one student.

On the other hand, the design of *WorkshopAR* failed to recognise the constant need of the students to jump in between applications and devices. The most important tool for work during the classroom session was the laptops or work tablets or the students, and *WorkshopAR* failed to acknowledge any other device as part of the experience, which caused the student to feel that *WorkshopAR* was detached from the workflow. An important lesson here, worthy of further exploration and expansion, is that supporting collaboration between people also means supporting collaboration between tools, or the support won't feel complete (check Cole and Stanton (2003) and Iglesias Rodríguez et al. (2017) for some early examples of these same issues in very similar contexts but with slightly different technologies).

Implications for the Research Goals

At the beginning of the architectural design exercise, it was identified that the technological development of *WorkshopAR* would provide interesting information to build a final answer for research questions SQ5 and SQ6. Previous sections already illustrated how creating choice and flexibility in the interaction design allowed for a higher impact in the user experience and added a sense of social relevance that the other tools created to manage or visualise the team failed to convey. Given these observations, it is possible to identify key elements that can be used to build the final answer for the related research questions.

For question SQ5, visualisation and flexibility were identified as the main advantages provided by AR technologies that could be used to create a significant impact in the student's experience. The students showed preference for unintrusive visuals that could be approached only when desired and that could be used in different contexts, conveying meaning and utility based on the situation without getting in the way of the work to be done. These observations could be extrapolated to any TEL intervention where it is important to consider that the learning activity and not the tool should be the centre of attention. In the context of a collaborative activity, it makes sense that the students would prefer for the tool to work as unnoticed as possible, providing aid and not hindrance. It is a delicate balance to achieve that requires a disciplined analysis of the feedback and a consistent iterative development.

The idea of flexibility guided the design when proposing the play model tools and the overall motivation of transforming any space into a working space. It was observed that this idea of flexibility could permeate even more elements of the design, such as the processes related to organising the team, organise discussions and communicating ideas through the application, which were originally too rigidly structured.

Some students welcomed the structure provided by the application, especially those having problems organising the group or needing explicit guidelines for their work, but it was resented by more organised or veteran students, who felt the activity was too restrictive. This hints at a need for structure, but allowing for workarounds and configuration. A similar situation was present when students found ways of customising their presence in the digital space and finding tools to create tailored forms of communication, which were initially considered but not given the importance they finally acquired.

All of these observations resonate very well with the educational nature of the tool: Useful visuals that do not steal the focus from the learning goal and a flexible structure that accommodates the different types of learners that could interact with the application.

Question SQ6 is more concerned with the opportunities created by a multiuser platform

for education, and the effect of mediating communication by technology. Creating a mostly transparent networking process was helpful to ensure that the friction created by the introduction of the tool was minimised as much as possible, giving extra strength to the idea that any technological intervention works the best when it is as invisible as possible. The usage of the tool itself was promoting social structures that were not desired (i.e., the responsibilities of the host user) and it was necessary to redesign the approach so that any social structure, goal or task assigned to any participant came from the own team management process and were supported by the tool, not enforced by it.

A final important lesson related to the multiuser approach was to not underestimate the importance of the social aspects present in any form of collaborative learning. It was possible to identify that there was a misplaced focus on promoting management and organisational skills through the pedagogical design of the activities, sometimes sabotaging equally important skills related to socialisation, communication and emotional management. This is true for both, the design of *WorkshopAR*, that found the most success among the students when presenting interesting forms of communication on top of the team management tools, and the case study in general, in which the students struggled the most with the social and communications aspects of the project rather than the technical ones.

5.3 Conclusions

WorkshopAR was the result of an iterative software development aimed at understanding positive ways of using AR technologies in a collaborative learning approach. The end result was a prototype that allowed the users to integrate into their workflow a set of tools that helped them to visualise all the components in motion needed for an effective teamwork and to actively participate in the procedures that make such work possible. *WorkshopAR* helped to illustrate and visualise all the elements and activities done when working in groups that sometimes are executed unconsciously and without acknowledgment of their functionalities. The software also helped to guide the discussion to the improvements that could take place for better results in the future and of the possibility of transferring the skills being developed into other scenarios.

Coming from an exhaustive design stage that identified several use case scenarios in which the students used WorkshopAR in their learning activities, and by constantly comparing the prototyped functionalities against the data obtained from testing, it is possible to highlight the three main elements provided by *WorkshopAR* that better align with the learning goals of the case study and that proved to generate the most value for the research context in which the development took place:

- **Working in a Shared AR Room:** Although immersion was not a main design objective for *WorkshopAR*, it was important for the students to identify that the activities done using the tool moved in a digital space that was in sync with their activities in the real space. The concept of the *digital room* was related to the idea of a space for working. Entering the *digital room* was equivalent to be part of the activity, and the Room was seen as a repository for digital content. But the Room also existed alongside the other tools and resources being used in the classroom (the workshops of

the course, the teaching assistants, the students of other groups, etc.) and the students were able to propose ways to integrate all of these elements in order to achieve the desired results.

All of these observations aligned very well with the original intention of the design and support the idea that *a sense of immersion* in the context of AR technologies include the physical space and many other elements outside the tool itself. This take on AR creates an advantage when it is important to not lose focus of the context in which students are learning, or when the context is also helping achieve their learning goal.

- **Having a digital presence in the digital space:** AR is a tool that works around visualisation and interaction. There was an important effort in the design and implementation process to create different options that capitalised on these advantages provided by *WorkshopAR*. The students resonated the most with the possibility of having a visual representation of themselves in the digital space, not only for personalisation and general socialisation, but as a point for interaction with their peers and the environment. Being able to see information about who is who and the tasks being performed created the biggest sense of *augmentation* of the activity and the biggest source of opportunities to work in the future.

- **Having visual and flexible tools for communication:** On a similar note, the tools provided for communication created a lot of impact on the activities of the students. The main takeaway from the observation related to these tools (discussions, emotes, pointers) is about flexibility and expression. The elements provided for communication were simple, expandable and context-independent, which gave the students the opportunity to use them in diverse scenarios and adapt them to their needs and preferences, highlighting the social nature of the application and an important avenue for future research.

The original set of hypotheses gave more emphasis to the interaction with play models and with the management of the team as the focal drivers of the activities in the classroom. That was clearly not the case, but it is interesting to observe that those activities emphasised the same high-level aspects of the experience: A rich visual interaction with the environment and access to tools for social interaction.

The development of *WorkshopAR* also served to explore different sets of tools and approaches to tackle the difficulties often found in many TEL developments, as identified in the literature. The technical challenges associated to teaching software are mostly related to the evolving and sometimes unpredictable needs of the classroom. Software that creates too much friction in its use is often abandoned. If the tool is perceived as unreliable, inflexible, or with a steep learning curve the benefits of using it does not cover its drawbacks.

WorkshopAR was not intended as a solution to these issues. It was an informed exercise that could provide insights by analysing the process followed and how different situations were handled (or mishandled). The documentation of the architectural design offered value by showing how the software and the learning design were integrated since the conception of the solution, based on the learning goals at hand and the adjustments done based on the input of the users interacting with the tool on-site.

In the same way, reporting the implementation process served as a record of the translation done of the initial design into a prototype. It highlighted the most important decisions and

the rationale behind them in light of the research and learning goals. It also showed what elements of the design worked and which did not, and the steps taken to ensure that the software was evolving based on data and careful analysis.

At the end of the process, it is possible to extract some lessons from the analysis of the results, based both on the limited scope in time and resources for the development and the rich opportunities for observation during the one-to-one contact with the users that the case study provided.

- **Students, teachers and developers need to be aligned.** These are often three different entities in the development process, and it is often the responsibility of the developer to coordinate and organise the other two roles for the purpose of the development. But it is important for the developer to understand that the teacher is the role that should be guiding the process, as it is the teacher who truly knows the issues and needs of the classroom (Gupta, 2022; Schmitz et al., 2023). It is also the teacher who needs to juggle the new technology along with the other myriad of elements that make a lesson possible. Equally important is to understand that the end user is the student, and that any teaching plan will fail if the student is not engaged. If the teacher is the one guiding the process, it is the student who shapes the final product (Ubaidillah et al., 2020; Vahedi et al., 2021).

  The development of *WorkshopAR* was successful thanks to understanding this line of work and maintaining a constant conversation with students and teachers, which helped in understanding what was not working and why. It was thanks to the help of the teaching staff that a good understanding was achieved of the context of the Industry Project course, but a better involvement of the side of the educator in the development process is needed, and this is a valuable line of research for future work.

- **Generalised vs Focalised design.** There is an appeal to propose a tool than can cover many if not all aspects of a problem. But an all-encompassing tool is a massive challenge, especially in contrast to the low scale and scope of many TEL projects. Even within the specialised field of collaborative learning inside the scope of *WorkshopAR*, the design could have focused even more on the functionalities offered to the students. A hypothetical third iteration could have focused on the social and communication aspects that resonated the most with the users, polishing the present functionalities and exploring more avenues of interaction in this area.

- **Technology ecosystems.** At higher levels of scholarity, it is important to consider that any technology used as a learning tool enters into a complex ecosystem of tools trying to cooperate (and compete) in aiding the user to achieve a goal (Alam & Mohanty, 2023; Omirzak et al., 2022). Even when a stellar functionality is offered, it could be eclipsed by a lack of connectivity with other tools or because it is a poor fit in that ecosystem. At this point, it is clear that this is a consideration mostly exclusive for tertiary education scenarios, but it is possible to imagine a situation in which a solution proposed needs to consider the technology used by teachers, administration and the institution in general, even at primary or secondary-level education.

This concludes the exploration and analysis of the development of *WorkshopAR*, of the process followed to ensure that the educational and technological goals were fulfilled, of the tools used to gather, analyse and incorporate feedback, and the evaluation of the results obtained to identify failure points and pathways for future work.

Chapter 6

Case Study: ENBU 79X/89X Industry Project

The objective of this chapter is to explore in detail the case study selected to assess the learning design that guided the implementation of *WorkshopAR*. The Industry Project course offered an ideal scenario to evaluate the collaborative premise behind all the proposals at the core of this research, being a course guided by strong teamwork and communication requirements.

The complexity of the course also opened the opportunity to analyse several factors that were not initially considered in the methodological design. Thanks to the open nature of the project and all the different profiles present among the students, the observations of the usage of *WorkshopAR* were able to capture interesting scenarios about the consolidation of teams and the variety of resources used by students to fulfil their academical goals. The teaching staff was also incorporated into the observation process, adding a distinct perspective to the use of *WorkshopAR* in the classroom and the implementation of collaborative approaches for teaching.

Section 6.1 will first provide an overview of the Industry Project course, its general design and learning goals, as well as the philosophy guiding that design as it could be inferred from the material available and the conversations held with the teaching staff.

6.2 will describe in detail the protocol followed for the observation proccess while sections 6.3 to 6.6 will present the main content of the case study, recounting the development of the course through twenty weeks of observations. The structure of the case allowed to organise the data in four major milestones, first described within the point of view of the course, followed by the intervention done with *WorkshopAR*, allowing for preliminary analysis and reflection for each milestone.

Finally, sections 6.7 and 6.8 will offer a description and analysis of the overall experience from the point of view of the students and the teaching staff based on the data obtained from the complementary research instruments such as interviews and questionnaires; followed by the final conclusions in section 6.9.

6.1 Description and Design of ENBU 79X/89X Industry Project

Industry Project is a last-year course offered by the School of Built Environments at Auckland University of Technology (AUT). The course offers students of the Architectural Design, Construction Engineering, Construction Management and Quantity Surveillance programmes the opportunity to experience a multidisciplinary project that emulates the procedures and circumstances often found in the construction industry.

Simulation is one of the key components behind the design of the course. Acting as a capstone course for several of the programmes that the School of Built Environments offers, the main goal is to expose the students to many of the scenarios and procedures commonly found in a construction project, while emulating several of the roles and tasks that need to be present in an architectural design or construction management firm.

The course covers little to no actively taught material, relying instead on the information presented in previous years. The learning goals focus more on providing a hands-on experience through challenges and scenarios that could be found in real-life projects, promoting the development of the skills necessary for the design, communication and planification of a solution, as stated by the course goals:

- Propose, organise, design, analyse, execute, and reflect on a multi-disciplinary project.
- Apply existing construction and engineering knowledge and skills to the project.
- Conduct a systematic literature review to identify works previously undertaken and gaps requiring research.
- Demonstrate initiative and independence in decision making where appropriate.
- Present project progress and technical details to multi-disciplinary audiences.
- Deliver and present comprehensive client reports at relevant professional standards.

The learning goals of the course align with the ideas promoted trough the learning intervention with *WorkshopAR* in key aspects like decision-making, communication, and multi-disciplinary, multiuser work. Industry Project offers the opportunity to apply the knowledge and skills that the students have gathered through their career in a situation that requires the collaboration with other professionals to fulfil the goals of the project.

The methodology of the course helps the students in the development of the project through three main mechanisms: the client simulation, weekly workshops, and open work sessions. These three elements feed on each other to help the students immerse in the development of the project in a way that simulates real work experience. This simulation involved a substantial effort of creating the context of the project with the help and input of several professionals, both part of the faculty and from external sources. The project asked the students to analyse:

- Geotechnical data of the terrain to be developed.

- Cultural, economic, and social factors of the zone where the site is located.
- Requirements and proposals from the client.
- Requirements and proposals from other stakeholders like the local community and the government.

The fictional client is represented by several experts, most of them part of the faculty but not of the teaching staff, referred to as Task Leaders. They are available to answer questions about their requirements for the project and about the work expected from each of the four roles present in the course. Additionally, each group would act as a task team in charge of the design and management of the development of the construction project. ENBU 79X/89X acts as the capstone for four different programs, and each group had at least one representative of each role: Architectural Engineer (AE), Construction Engineer (CE), Construction Manager (CM) and Quantity Surveyor (QS). The group was expected to coordinate efforts to create a coherent proposal for the construction project, while fulfilling specific tasks and deliveries specific for each role. Finally, the group had to provide weekly and milestone reports to the client, communicating the state of the project, the creative decisions made, and the management process proposed to oversee the construction.

The course relies entirely on the project approach to address the learning outcomes. There is no taught content in the course for any of the roles, relying more on access to material of previous courses and curated information on the web, all through the LMS used for the course. A second support tool for the technical content is the presence of the Task Leaders, who can be consulted about the requirements for each role, for feedback about the work done or for recommendations on how to complete the deliveries.

The main approach used by the course to convey course content to the students is through the weekly workshops. These take two possible forms: workshops guided by the teaching staff, which are meetings used to clarifying aspects of the project, or workshops guided by external professionals, used to talk about subjects useful for professional development, like team management techniques and current trends in the industry.

The final methodological implementation of the course are the open work sessions, which represent most of the time spend by the students in the course. As the name suggest, they are open in nature, allowing the students to use the time in the classroom (about two sessions of 1 hour per week, depending on the length of other activities) to meet with their group or with other students to organise their work and progress towards the competition of the different deliverables. These sessions also allow the students to have direct access to the teaching staff and a somewhat reliable access to their peers.

The assessment of the course is completely individual. Deliverables and the proposed solution to the project are built as a group, but at the end, each student presents their own contribution. The main assessment tools are oral presentations and client reports. The presentations consist of short 5-minute poster expositions about the overall proposal of the group for the project, the current state of development and the personal contributions of the students in that proposal. There are two oral presentations along the course, one focused on the architectural design and the other on the final proposal.

The client reports consist of weekly formative assessment of the group's progress and two final reports at the end of each semester. The biweekly reports are not marked but are

analysed weekly to give feedback to the students about issues found in the reports. It is also a useful tool to identify the overall progress of all the groups and to take decisions on how to manage due dates and marking expectations. The final report is marked and consists of a quick summary of the personal contributions of each student to the project, as well as a reflection of the work done by the group, the problems found and the steps taken to solve them.

As for the content of the project itself, it is meant to cover activities for each of the roles of the course. The specifics of the content of the project are not that necessary for the analysis of this case study, but overall, the students must propose a solution for:

- An architectural design for a building complex that considers the geotechnical data of the construction site, the functional necessities of the project and the complications and peculiarities found in the selected site.
- A construction plan that considers building materials, functional necessities and local regulations.
- A detailed schedule for the management of the construction, considering aspects like budget, necessary contractors, needed studies and the impact on the local community.
- A detailed consideration of the local construction requirements, the legal implications of the design and external factors like the economic and ecological impacts of the proposal, as well as the consideration needed related to the Waitangi treaty.

It is important to remark that all these objectives are evaluated on two fronts. First, the work done by the group, how information flows across the different roles, and how work is coordinated to create a coherent proposal. This aspect is mostly assessed through the oral presentation. The second front is the individual contribution and performance of each student, marked mostly by the accuracy and quality of the tasks completed, and evaluated through the final client report.

6.2 Protocol

The case study was developed in three distinct stages with different set of objectives in mind. All three stages were meant to collect descriptive data about the development of the course, either to create a better picture of the context in which the course was happening, to gather descriptive data about the progress of the project or to ask for more granular opinions from the students and the teaching staff, all these with the goal in mind of creating a rich recount of the course.

6.2.1 Physical Documentation

Most of the written material was accessible for the teaching staff and the students through the LMS supporting the course. The LMS was the primary communication method used by the teaching staff, besides direct announcements at the beginning of a session. Students would find all the basic information about the project and the different deliveries of the course

in the LMS, and it became the main repository for the different forms and documentation needed for the coursework, such as client reports, presentation formats and assessment rubrics. Information about the structure, learning goals and methodology of the course was also found here. This information was used mostly to build a good understanding of the objectives and background of the course, as well as to establish a good idea of the work expected from the students.

Although most of the assessment tools of the course consisted of oral presentations, a good amount of material had to be submitted through the LMS, either as its own assessment or as a complement to the oral presentations. A lot of this material consisted of individual work and allowed for an interesting analysis of how the students were organising their work as part of the group activities.

Finally, the LMS portal also offered a discussion forum for the students meant to be the main communication channel between the students and the teaching staff outside the classroom. Activity here was almost non-existent before the semester break, and students only started to use it after the adjustments done to the course during the second semester. Following sections will detail this situation better, as it is an important point of analysis of the course and of the way technology is used in the classroom for communication.

6.2.2 Classroom Observations

The main source of data coming from the case study was the direct observation of students along the classroom activities each week. This is already a departure from the original methodology, which proposed observations of the groups outside of the classroom. It was evident during the first weeks of the semester that the students were using mostly the classroom time for their groupwork, opting for individual work outside the classroom and for asynchronous communication with their teammates. This situation called for some of the mechanisms of the observation process to change and adapt to what the students where really doing, but the general approach and goals for this stage were the same.

There were three main types of observations that composed most of the data collected. All types focused on describing in as much detail as possible the type and objectives of the activities being observed, the outstanding characteristics of the students participating and any relevant information about the background that was possible to collect. All observations were recorded using mostly personal notes and video recordings when it was possible to do it without disrupting the classroom too much.

The first type of observations was of general activities for the whole classroom, guided normally by the teaching staff or by a guest speaker. These activities included all the students and were not directly related to groupwork, although they often required the students to group based on their assigned roles.

These observations were useful for understanding the general structure and dynamics of the course, especially those relations between the teaching staff and the students. These activities were often used to deal with general questions from the students, for the administration of the course and to observe the different workshops held throughout the semester.

The initial categorisation of themes for these observations was very general:

- Guidelines from the teaching staff to the students about teamwork and collaboration.

- Feedback given to the students about an activity or a material produced for the project.

The second type of observations was of the general groupwork performed by the students. These *work sessions* often involved more than one group at a time, and the focus was on gathering information with minimal intervention, sometimes asking quick questions to clarify a situation or to get a better idea of the context.

These observations helped in identifying the general dynamics of the groups, and the activities being completed for the project. They also constituted the baseline observations for those activities that were not using the AR tool and became the main point of comparison with the other observations.

Initial categorisation here was more varied. In one hand there was a group of themes searching for the collaborative strategies being used by students:

- Activities and resources to organise and manage the team.
- Recurrent roles (beside the project's roles) and relationships being created among the students.
- Mechanisms to take decisions and resolve conflicts.

A second focus was the use of technology and trying to identify tendencies about what activities were mediated by digital tools:

- Technologies used to produce content and fulfil learning objectives.
- Technologies used to access and consume content to create and/or transmit knowledge.
- Technologies used to mediate or facilitate communication and social relations.

The third and final type of observations were of the instances in which *WorkshopAR* was used in the activities of a group and if it was changing in some way previously observed behaviours or promoting new ones:

- Instances in which a problem was solved using *WorkshopAR*.
- Instances in which a problem was created because of the use of *WorkshopAR*.
- Behaviours promoted using *WorkshopAR*.
- Social activities taking place within the digital space of *WorkshopAR*.

These observations were more guided, prompted mostly by the researcher, asking the students to explore one or two features from the software, asking for feedback and identifying instances in which the tool was used or mentioned without prompt.

6.2.3 Unstructured Interviews

The final dataset comes from unstructured interviews conducted with a random sample of the students and of the teaching staff. Both interviews focused on gathering information about how participants saw collaboration as part of the development of the course, how do they perceive their own collaboration skills and how the course was helping them to develop or improve those skills.

The interviews with students focused more on trying to reconstruct the team dynamics of those groups that were not directly observed, asking questions about activities done to fulfil the requirements of the course, rules or decisions taken to manage the group and how effective did the students found those elements.

The interviews for the teaching staff were one-to-one conversations about what they perceived as effective collaboration and how did they evidence, if at all, those ideas in the work done by the groups in the course. These interviews were used to gather information about the development of the current cohort of the course, the challenges and complexities in managing the course and more personal opinions on the quality of the student's work and what could be done to improve the course in general.

Appendix C of this document shows the script used for each interview.

With the learning objectives of *WorkshopAR* detailed, clear mechanisms proposed for the students to fulfil those goals and the documentation of all the types of observations proposed, the next set of sections will now recount and analyse the execution of the Industry Project course.

6.3 Weeks 1 to 4: Team Consolidation

The first weeks of the course were characterised by a period of accommodation. The Industry Project course offers a unique experience, and although the students at this point have already experienced project-based approaches in the past, none had been in such a multidisciplinary context, nor with such an emphasis on simulating a professional setting.

For the activities with *WorkshopAR*, it was also a period of introduction, letting the students familiarise with the dynamics of the course before adding the extra layer of complexity that of the observations and the usage of the software.

6.3.1 General Observations

Classroom sessions took place on Friday mornings across two big arrangeable lecture rooms, needed to accommodate the approximately eighty students enrolled. The space provided several tables that could be moved, separated, or merged to create different configurations, ideal for the dynamic groupwork that the course was relying the most on. The rooms also enabled the constant flow of people and activities present in one session, as described in Section 6.2, and provided ample space for each group to work comfortably using their personal equipment.

The very first session of the semester set the tone and flow for all the other sessions, which followed the same template. Students arrived within the first ten to twenty minutes of the session while the teaching staff prepared the room and discussed the activities of the day.



Figure 6.1: Main Lecture Room

Table 6.1: Weekly Karakia

Te Reo	English
Mauri oho	Life force awaken.
Mauri tū.	Life force stand tall.
Mauri ora ki a tātou.	Life force all wellness, good health for all.
Haumi e, Hui e! Tāiki e!	Join together, unite, the group is ready to progress for the purpose of coming together.

As it is tradition in almost all the Built Environments programs (and many other programs at AUT), the lecture started with a Karakia, a traditional Māori prayer to open any social meeting or significant event, which Table 6.1 shows in its Te Reo and English versions.

Although it is a simple detail and a bit detached from the overall objectives of the observations, the Karakia became a constant reminder of the tone and mindset needed for a successful experience in the course, and a tradition that reminded the students that they were entering a place meant for working together.

The first discussion during the introductory session was on tips and recommendations about how to handle the stress of the course, a very telling detail. Industry Project is designed to be a complex course, that complexity is what allows the students to gain experience in a project close to what is found on the industry, but it also causes a lot of friction for the students who are trying to manage all the academical requirements of the course.

The discussion asked the students to think on the requirements of the course from two

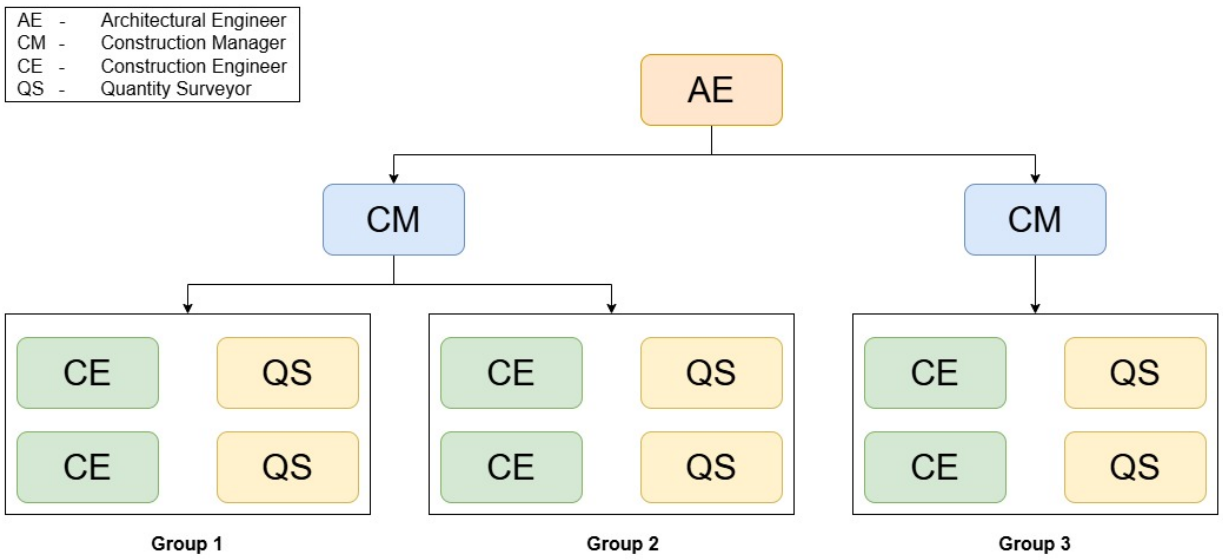


Figure 6.2: Distribution of Shared Roles in the Groups

views: the individual responsibilities to complete each of the deliveries and the contribution there are giving to the shared project. The lecturer stated very clear recommendation for this purpose:

- Be proactive with work, decisions and resources. Don't assume that everyone knows what is happening.
- Work together; the whole project cannot be finished by one person.
- Distribute and communicate. Remember that team management also needs time to be completed.

The biggest challenge of the project was that each of the disciplines represented in the group had a piece of the information and the expertise needed to complete it. Communication and proper management were a key aspect to successfully propose a coherent solution. This was the core design of the course, and it was communicated to the students from the very beginning.

The third theme of the first session was the issue of group assignation, a completely administrative tasks, but by far the most important activity, at least from the point of view of the students. The composition of the groups tried to accommodate two students per group of each of the roles: AE, CE, CM and QS. The number of students in each program did not allow to cover all spots, with an approximate ratio of two quantity surveyors and construction engineers per construction manager, and only 3 AE for all the groups. Figure 6.2 shows a simplified example of the distribution of roles used so that the available AE and CM could be shared between different groups.

With this configuration, the groups were forced to share the work of the AE and propose their own twists and takes on the common ideas present in the classroom. In the same way, one CM often had to coordinate the activities of at least two different groups. Intentional

or not, this situation required a lot of effort to coordinate the different roles in one group, and a disciplined flow of information from the AE all the way to the CE and the QS. The situation matched perfectly with the learning objectives of the course, albeit introducing a lot of administrative hurdles for the teaching staff.

For the observation protocol with *WorkshopAR*, it meant that the cohesion of the groups was weaker than expected. Some students only needed to work with one specific group and one set of overall goals, while others were required to constantly move between groups and solve different types of problems. Later it was observed that students preferred to work with other people of their same role, blurring the boundaries between groups and creating a lot of horizontal communication between students.

First Bonding Exercise

After most of the students found their group, the rest of the time was used for what could be considered the first workshop activity of the semester. As with the introduction, the main purpose of the workshop was to set the tone of the activities needed for the course and to create the correct mindset in the students about the requirements of the project. The activity was also used as a way for each student to introduce themselves to the group.

As an icebreaker the lecturers proposed a simple discussion about the steps needed to bake a cake. The purpose was to create a debate in the group about quantity vs quality in the development of the project and about procuring the proper ingredients for the chosen approach. The reflexion was that such a discussion must take place at the beginning of their project, and highlighted the main activities that the group should be executing along the life cycle of the project:

- Identify possible option to solve a problem.
- Discuss with the group all options and pick one.
- Work on the individual deliveries of the project based on the option selected.
- Communicate to the client the reasons behind the decision and the results of the work done.

This activity helped in creating observations of how different students approached that first contact with their group. Later, in the analysis process, those observations would be used to discuss with the students possible scenarios in which *WorkshopAR* could have helped in those activities, since it was not possible to intervene with the software at that early stage of the course.

Team A was a good example of what was observed during this activity and, along the description of other teams in future sections, a good exercise to anchor the observations to one easy-to-describe point of view that represents what was observed in other groups during the same activities.

Team A was mostly complete, all roles were present in the discussion except for one of the QS. For most of the students, this was the first time meeting each other, therefore their first conversation was not related at all to the activity, but focused on presentations,

interchanging names, their current program (which was related to their role) and contact information, mostly phone numbers, Instagram or Facebook.

Although the purpose of the activity was to formulate the main value proposition of the group, a rough idea of how the group would distinguish their proposal from the rest, the discussion taking place in Team A centred more on trying to understand the premise of the project itself.

Those groups closer to the lecturers engaged more in the discussion about the value proposition, with constant interventions, questions and feedback from the lecturers. Further away, groups like Team A defaulted more to idle chat or to those discussions about the exact work needed for the project, like the specific tasks they had to work upon and what was supposed to be the purpose of their role. They were having problems identifying that information and a lot of questions started appearing among them.

The lecturers eventually spread around the room and talked with more groups, noticing the questions piling up. The general answer was that the project consisted in one proposal from the group that had to be communicated to the client through the individual deliveries of each member. It was also remarked that more details about the project would be discussed in the following sessions, and that all information about individual activities could be found in the LMS.

From the activities and observations gathered during that first session, it was already possible to generate a couple of ideas about the design of the course that could affect the development of *WorkshopAR* or be the source of interesting data:

- Mechanisms used by the students to navigate the complexity of the course.
- Differences in approaches and attitudes between those students engaged with the activities of the course and those falling behind.
- Mechanisms implemented by groups to manage the flow of information needed to fulfil the requirements of the project.

Q&A Sessions

The initial reaction of confusion from almost all groups was expected, and the teaching staff had already prepared the second session of the course for a Q&A session. The idea was to keep up with the simulation, with the lecturers acting as the clients and providing information about the project, but it was also used to clarify details about the deliveries and the marking criteria.

Figure 6.3 shows how the room was organised for the activity. This setup is relevant because it became the default configuration of the classroom for the rest of the semester. For explicit Q&A sessions and many of the workshops, the lecturers would ask the students to organize in this configuration and encourage students of the same role to work together and exchange information. For the open work sessions, students would still use this setup to easily find other companions with the same role when needed, compare work, and ask questions to see if someone had the answer.

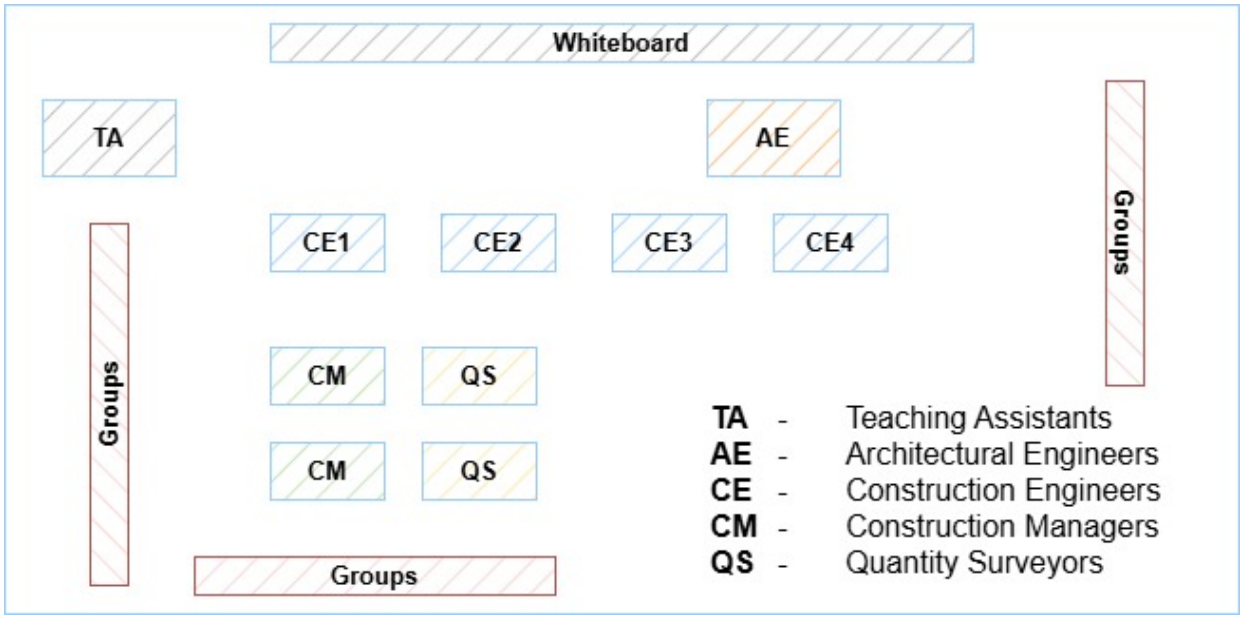


Figure 6.3: Distribution of roles during Q&A sessions

Groups would still work together in the available spaces around these central tables, but movement would be constant, with students coming and going between groups and approaching one of the role tables if in need of information.

Some other aspects of consideration about this configuration of the classroom. First, the centre-stage position of the AE. Since there were only three students in this role, between five and six groups (an average of 15 to 20 students) depended on the work and decisions of one of the AE. The structure of the project also required for information about the architectural proposal and design to be the first element to be ready, and all the other roles had to wait for this activity to be completed before being able to start working on their own responsibilities. Additionally, any question or change to the proposal had to flow back to the AE, and the response had to come back the same way, creating a lot of overtime of just waiting for responses that may not even come back.

The second aspect of notice was the Teaching Assistant (TA). The TA group was very large, eleven different assistants, at least 1 representing each role. Often, the responsibilities of any TA would be to help the groups during the open work sessions, answering questions about the project and giving quick feedback to any work in progress. Each TA would do his or her best to help the students, but since each role was represented in the team, it was common for a TA to not have an answer at hand, finding the need to refer the students to another TA or to the lecturers. The students quickly found easier to approach the TA table, ask their questions to everyone and see who could answer from all the people present in the table.

The Q&A activities established the main workflow for all the students, at least for the first milestone of the project. This configuration of the classroom highlighted several elements in the development of the course activities that where not part of the initial design of the *WorkshopAR*:

- The crucial participation of the lecturers and the TA team in the workflow of the groups.
- The constant movement of students between groups.
- The initial central focus of getting information from the role tables and bringing it back to the groups.

6.3.2 Intervention with *WorkshopAR*

During the introduction of the teaching staff in the first session, the lectures acknowledged and presented the research project to the students and the ongoing observations taking place in parallel to their work. Given the complexities of the first couple of weeks, no further direct mention of the research was done, with the idea of not adding up even more elements to the already congested list of things that the students had to take care of during those first weeks.

Regrettably, this meant that all the activities that could be classified as part of the first acquaintance and consolidation stage of groupwork (Lowe & Herranen, 1982) were only part of general observations, as described in the previous section, and no direct intervention with *WorkshopAR* was done.

It was not completely impossible to gather some data and direct experiences with the tool about the first encounter process, though. Most of the data and feedback from usability tests and observations about the profile and user anchor features can be found in section 5.2.1, which are functionalities related to the consolidation stage of the group. Additionally, an observation that took place later in week 6 offered relevant ideas for this scenario.

Consolidation Stage

The proper introduction and description of the observed group will be done later in Section 6.4.2. For now, it is enough to mention that the group was asked to interact with the profile creation and the user anchor once they created and joined a *digital room*. They were directly asked to remember their experience during the first two weeks of the semester and to try to imagine if something of what happened could have been different (not necessarily better) if *WorkshopAR* would have been available to them back then.

Some responses stood out from all the comments given by the students while they were looking around the *digital room* and mostly playing with the telescopic gaze of the user anchor once they found that feature. One of the students mentioned that having a digital space where all the members of the group could be represented and have a presence would have been useful to create a sense of belonging to the group from the very beginning.

They quickly referred to the initial chaos of trying to find their group. Most of them only had the number of the group as a reference, very few knew each other, and even if they did, there was a high chance they were not in the same group. One of the students commented that he ended up shouting his number until he found his other companions, prompting giggles from the others who were remembering the scene. Although humorous, the students confessed that it was unnecessarily stressful, and that the only other resource to find their group was a huge diagram in the LMS that they were having problems interpreting (the same diagram used to create the simplified version of Figure 6.2).

The students related this anecdote to *WorkshopAR* by noticing that they could personalise the colour of the user anchor (see Section 5.2.1), and that the selection palette (accidentally) resembled that of the diagram in the LMS. The students commented that the use of colour plus the visual anchor in the AR space could have been used to quickly identify other group members or at least other similar roles, as the configuration of the classroom was asking them to gather with other students of the same role.

This described functionality was outside the designed use case but reflected well the idea of using visual cues created by AR to convey a sense of belonging or identity in the group. A similar set of ideas were discussed about the information that could be displayed when interacting with the user and room anchor.

The second major discussion was an interesting set of ideas about the technology used by the students to establish first contact with their peers. Their comments reflected well what was later identified in interviews with students: students preferred to first establish a proper channel of asynchronous communication and resort to more direct contact only if it was needed. One of the students even commented that she did some *stalking* of one of her companions in social media to see who she was working with.

First Open Work Session

Regarding the weekly work of the course, students quickly found that they could gather in the classroom, organise the work needed for the week and assign individual tasks to be completed outside the classroom, relying on communication tools for quick questions and catch-ups. Since no group was working outside the classroom, the observations using *WorkshopAR* had to take place during the weekly sessions, which forced some changes to the protocol:

- Interact with only one group at a time and to not take the whole time of the open work session, to not interrupt the work of the students too much.
- Minimise disruptions to other groups and to other activities of the classroom. This often meant using more discrete recording methods, relying mostly on audio recordings and the field notes of the researcher.
- A focus on testing specific interactions with *WorkshopAR* rather than the initial proposal of a more unscripted access to the tool. This approach was quicker, could be slotted easier in any schedule of activities for a classroom session and would interrupt the work of students the least.
- Not targeting the same group several times in a row. Although a lot of the subsequently discussed data comes from the same group, mostly because they were happy to keep collaborating with the project, all observations were done in sessions with enough time in between and at different stages of the project, so that the process was not a burden to the students.

With these new considerations, the plan was now to pick which features to introduce or focus upon for an observation and to move questions and conversations to more specific points. All the observations of the use of *WorkshopAR* that follow will have the same structure:

1. Let the students organise themselves and decide or discuss what are they going to focus on during the *work session*.

2. Introduce *WorkshopAR*, either from the very beginning or just the focus features for the observation.

3. Let the students explore the functionalities, with the researcher asking questions to prompt discussion or to guide the students to a particular interaction with the application. Gather and record observations.

Initially, the group volunteering for an observation would move to a different table in one of the rooms which was more secluded from the rest, with the idea of being able to talk and record without disrupting the other groups. It ended up not being a good idea, because moving between rooms took away time from the observation (and from the student's work) and limited the group's access to the TA group or from the lecturers.

The following observation was of Team B during week four. The team had four members during this activity, two QS, one CE and one CM. The group decided that the main objective of the session was to work on the first poster presentation, which will be detailed in the next section. For the observation, the proposal was to focus on two interactions:

- The *digital room* configuration.

- The profile configuration and the user anchors.

WorkshopAR was deployed on two different smartphones and given to the students, which meant that in practice only two students were interacting with the software at the same time. All the students had their own laptops and were working on them when not directly interacting in the observation activity.

The first step was to create and configure the *digital room*. One of the QS took the initiative to be the host and quickly moved through the technical steps all the way to the creation of the *workspace*. Defining the session goal did not take a discussion at all, since it had been already established previously. The mention of the goal setting did prompt the question: What would happen if the goal had not been discussed earlier?

The response was a bit vague; the group had a clear idea of what was the work needed for the session, but it was not clear for them when they took the decision of dedicating the session to start working on the poster. The CM did mention that the poster was the next deliverable, so there was no need to discuss what to do next, it was mandatory to work on the poster, and a matter of focusing on their own individual responsibilities.

The CM continued this train of thought, proposing the scenario that if the lecturers expected a more step-by-step type of meetings, more formal approach to the group work, that would be his main responsibility, and it would be clearer, at least for his role, what to do in each session. For now, he was feeling a little lost.

Figure 6.4 shows the space used for the couple of observations that took the groups apart from the rest of the classroom. The setup of the table promoted a behaviour that had already been seen during the usability test: the student tried to create a *workspace* that fitted in the entire table, although it was not necessary, and was struggling with the controls and had to



Figure 6.4: Initial Space for Observations of *WorkshopAR*

stand up and move around to try and cover the whole table. She was not happy with the result and asked to restart the process to create a better *workspace*.

While repeating the creation of the *digital room*, the student commented that the CM should be the one in charge of the configuration process and handed the mobile to him so he could do it. The situation prompted an intervening question: Should the same person always be the host? How would they organise the group to create and configure the *digital room*?

First, they proposed that it would make more sense if someone had that fixed responsibility but found little reasons to keep that idea when following the discussion further. They argued that *making* the *digital room* should be a fast process and that the first person to arrive to the classroom should do it. This approach was easier and would make the configuration time needed for the use of *WorkshopAR* shorter.

The interactions with the user anchors also promoted some discussions about the use of the tool in the activities planned for the session. The students liked the idea of the user anchor, they specially found amusing the *goofy* look that the gaze gave to the whole visual, and suggested more elements of customisation beside colour, like text, shapes, or animations. They also mentioned that the functionality was more suited for the first two weeks of the course, when it was more common to need information about someone, like a name or a role, and was easier to fit the playfulness that the feature was promoting. For the work that the group was doing now, the feature was rather useless, since they already knew each other and had other means of getting in contact if needed.

Other two important observations to mention that were not necessarily linked to the use of *WorkshopAR*, but that were relevant to the dynamics were appearing in almost every

group:

First, when setting themselves up to start working, the CE noticed that, based on the goal they had established of working on the poster, he had a lot of gaps in his understanding of what he should be doing for the activity. The group tried to use the information found in the LMS to clarify the situation, but it was not enough, and a TA had to intervene.

The second observation was that the work done by the students was very individual in nature. They were working together physically, often sharing comments and information, but in the end each one concentrated in their own work. The CE needed to clarify his doubts about the same poster all the others were working on, but because none of his teammates shared his role, they did not have a clear idea either of what the CE should be doing.

6.3.3 Preliminary Analysis

The first four weeks of work were a period of contextualisation and adjustments. Students were prepared to tackle a course that was known to be complex, and their first concern was to untangle the complexity and start working on the project as soon as possible.

The first issue that the students found, one that the teaching staff had to quickly acknowledge, was a limited access to information. The LMS was obscuring the requirements of the project in between links and tons of external material, and the teaching staff had to explain and repeat several times the same information. Activities like the Q&A sessions and the constant access to the TA staff helped the students to clarify any doubts, but those were resources that only the groups consistently attending the classroom session had access to.

The interactions with Team B showed that using the structure that *WorkshopAR* was proposing, especially for assigning goals and tasks, helped to incorporate those elements to the organisation of the team. It was especially useful when the goals were not clear or had not been discussed enough. That was an exceptionally good behaviour promoted by the application and aligned with the learning design proposed.

The main functionality of *WorkshopAR* was understood by the students but its immediate value for the project was not really seen. The main point of comparison so far between *WorkshopAR* and what other groups were doing was the creation of relationships by using the available technology. It was observed that most groups did not think too much at first about the in-person communication needed to work and were primarily concerned with establishing points of communication that are asynchronous in nature (WhatsApp, Teams, Facebook).

Students commented that they preferred to first establish a relation through social media and communication technologies and then step into face-to-face work for more complex tasks. A quick analysis of works like An and Frick (2006) and Robinson and Stubberud (2012) give some validity to this idea, showing that students prefer quick, simple communication via their preferred apps, but appreciated more face-to-face work for more complex work.

6.4 Weeks 5 to 9: Poster Presentation

The work done by the students all the way to week nine focused on one single activity: the first poster presentation. This activity was individual; each student had 5 minutes to present

their poster to the teaching staff. Despite the individual nature of the presentation, there were some key points that required group coordination:

- Each group was associated with one of the three AE working on the course, which meant that design proposals were shared among separate groups.
- Each group had to take a communal decision of the main or signature material to be use for construction (timber, concrete, etc.) and base the project on that decision.
- All groups had to present the same major topics in the poster: a design proposal, an analysis of the contextual factors of the project (legal, ecological and the community) and a preliminary analysis of costs.

To fulfil these criteria, information had to constantly flow from the AE, who originally proposed the design, to the CE and QS who had to analyse the proposal and build a construction plan, which often required going back to the AE to clarify elements about the proposal or to offer feedback about the feasibility or viability of some aspect of the design.

Managing this flow of information was the major challenge front he students at this stage and constituted the biggest instance of collaborative work observed in the course. AE, CE and QS had clear goals, and once the issues of coordination and communication were solved, students could work steadily towards their own poster. The CM, on the other hand, had a challenging time understanding their role in the group, and what was expected of them in the poster presentation.

The bulk of the observations for this section consisted in that: how different groups solved (or failed to solve) the information flow issues, how much they collaborated inside and outside the group to finish their individual work and how *WorkshopAR* was later introduced to try and help in those steps.

6.4.1 General Observations

Weeks five to nine represented the biggest instance of collaborative work observed through the entirety of the course. The poster presentation was an individual activity but required group coordination for good final presentation. The group had to work together on the analysis of the proposed design, on basic decisions about the direction of the project, on a coherent cost analysis and a consistent look or brand for the team across all aspects of the project. Each individual activity needed information from the others, and there was a clear flow of information between roles.

At this point the groups consistently assisting and working on the classroom sessions had divided in two distinct categories:

- Groups that collected all the information needed and were progressing in different areas of the presentation.
- Groups that had not been able to communicate well and had not gathered enough information to show any substantial progress.

The following general observations detail the dynamics of teams clearly showing on of these two characteristics. Following the new protocol, it was possible to observe their work based on the plans they had for the session and later introduce *WorkshopAR* to contrast how the tool changed or influence their approach to the proposed goals.

In both cases, the teams were working in the central layout of the room, that is, the tables assigned for Q&A activities and that represented the easier way to have access to the information needed for the poster. The AEs would normally work in that section of the room, which meant it was the best time to have a conversation with them, as well as with other students or with the lecturers. It also showed how much the groups mixed and moved around the room during that data collection period and later settled down to work in their individual assignments.

A Bad Example: Team C

Team C was represented only by two people, both in the role of QS. By their own assessment, they were having a lot of problems finishing their individual posters because they had no concrete information that could be translated into a cost calculation (the main objective of the QS at this point). Their goal for the session was to compare their work with others and advance in the creation of the poster.

When asked to elaborate on why they thought they were having so many problems completing their work, the answer was fast and clear: they had had little contact with the rest of the team in the last weeks. They described the communication of the group as broken because there was always missing information or a lot of uncertainty when asking anything through the group chat. Information was always provided at the last minute, and they had seen each other waiting without gaining any progress because there was no response from one or more members of the team.

Groups had a lot of interactions between each other, and information did not only flow vertically between the different roles, but also horizontally between the groups. Students were working around the limited access to the AE by getting answers from their roles in other groups, adapting, or directly copying information among them. Since Team C had only two members present, they were working near another group and interacting with their CE, since their own CE had never appeared in class and the students themselves reported to had never seen him in person.

The situation was not the best for the group, but the students had managed to use different workarounds to get the information needed and progress with their work. The structure of the project also allowed them to focus on their individual assignments and to not worry much about the lack of group cohesion, to the point that they were not genuinely concerned about the work of their teammates. It was a situation that eliminated some of the stress but that ran in contradiction with the objective of the project-based approach.

A Good Example: Team D

Team D had a CM, a QS, a CE and one of the AE was also directly working with them during this observation. The CE was the most interested in working next to the AE, since he needed clarification about the technical aspects of the design, and ended up working more

next to him rather than with his group. That did not mean that the rest of the group was not participating, it was possible to observe that every time the CE had new information, the CM and the QS would quickly catch up and compare notes. If there were questions, the CE would go back to the AE and would try to find a quick answer, then everyone would go back and work in their own laptops. Communication was short and to the point, collaboration was minimal, but it was efficient, and the QS directly commented that she had finished the biggest portion of her work during that session.

The horizontal flow of information was also seen in here; the lecturers would encourage the students to use some of the tables in the room so that all QS or all CM would talk with each other and could clarify doubts about the deliveries. The students did not used those tables that much, but it was common to see students going from one group to another with their tablets or laptops asking questions or interchanging information.

6.4.2 Intervention with WorkshopAR

The previous section showed the overall dynamics created in the groups for the competition of the first assignments, and the most relevant challenges around the flow of information and the communication issues within the group. For the second intervention with *WorkshopAR* the objectives for the observation were the following:

- Introduce the play models to discuss the aspects of the project related to the design proposal or to any activity related to the physical aspects of the project.
- Introduce the annotations as a tool for communication and management of information.
- Introduce the debates to aid in the discussion and decision-making process of the group.

The annotation and debate features were still in an early stage of development, and the observations focused more on the interaction with play models, but it was possible to show their main functionality with the objective of identifying what elements could be refined or added during the second iteration of development. Despite the crude state of the functionalities, both annotations and debates were well received, and it was possible to gather direct interactions and feedback for those features.

The observations will follow Team C and D again, as introduced in the previous section. In both cases, *WorkshopAR* was quickly introduced to them, the major controls were shown, and the group was given time to explore the configuration of the tool. After that, the focus was on the objective features.

Annotations and Debate Features

Team C interacted the most with annotations, and after briefly testing other functionalities like the user anchors and the debates, they agreed that the annotation feature was the one they could be using the most.

Their immediate comparison was to the tool Miro [1], a whiteboard-like application that both students were using to organise their work and to share ideas. They associated to

[1] https://miro.com/



Figure 6.5: Team D Working on the Room Configuration

the annotation feature the same ideas they could explore in Miro: a repository and visual representation of a project, helping at activities like brainstorming and free association of ideas.

Given this comparison to Miro, they were more interested in exploring the relationships that could be created between annotations. They recommended that it could be useful to have some way to make these relations explicit by adding connectors like arrows or chains between annotations. The association of the annotation to the physical space did not strike them as relevant or charged with meaning, but they did select a nearby wall to group all the annotations they were creating and called it the *ideas board*.

Team D, on the other hand, barely interacted with the annotations, with one of the students remarking that the feature could quickly be abused to be rude to someone or to just clutter the space with rubbish. The idea of using another tool as a visual repository of ideas was discussed before the interaction with *WorkshopAR*, but none of the students at Team D used something for that purpose, and could have been the reason they did not related to the annotation feature as much as Team C.

For both teams, the idea of expanding the annotation feature with graphical elements other than text was also immediately discussed, especially if it could be possible to access the camera or the photo storage of the phone.

Comments around the debate feature were the other way around. Team C did not have the need of using such a feature, since there was only two of them. They argued that such a tool would make sense only for big teams, ten or more people, where it was possible to not know someone or for the necessity to manage the chaos of so many people trying to decide something.

In contrast, the debate feature resonated the most with Team D. During the session, they had to take decisions regarding the construction material and some changes needed to the design. While testing and exploring the functionality they even recreated a previous discussion about the selected construction material. Upon seeing that they had four slots for the vote options, the AE commented if it was worthy to discuss the addition of a third material. The other students, panicking, responded with a big no, considering all the work they had already done with the original decision.

It was good that the tool promoted a deeper thought about the options of the debate and helped to flesh out the discussion, but it also showed that the users felt obligated to configure all the options available, even if it was not necessary. This pointed to the need of tweaking the configuration of the debate. In the same line, it was discussed that the configuration was taking too long for simple questions that could easily be asked aloud, echoing the comment of Team C that such a feature could be better use in a bigger and newer team in needed of more control and management.

Play Models

Team C barely interacted with other features beside the annotations. They tested the interaction with play models, enough to offer some data about the controls and how the improved control scheme was causing less problems in comparison to what was observed during the unstructured test. The group commented little about the tool and could not relate the feature with their current work, as other students did in the past when interested in a functionality.

Team D offered a more telling interaction with the play models. The students tried for longer the actions related to the control scheme of the feature. They spent the most time positioning different models around the space and sharing the interaction with their companions. They even took turns to interact with this feature the most.

It was possible to gather a lot of information about the interaction design, the UI, and the way to signal the protocol for shared models, as explored in section 5.2.1. The experience was not flawless, but the idea was clear to the students, and it was easy to identify and plan the needed adjustments that could be implemented for the second iteration. The observations about how the tool integrated with the activities of the project was not as good.

This observation was a unique opportunity since both, an AE and a CE were present in the session, the two roles that could benefit the most from the play models. Additionally, the group was communicating and understanding information about the architectural design, one of the intended use cases for the feature. The situation was perfect and yet there were a lot of issues.

The first problem was that the tools the AE and the CE already used to create the architectural design were better suited to work on changes and faster to show the results. Both students, when testing the tool, remarked that the play models could fit in the very initial discussion about the design, while gathering and drafting ideas, but once the work started seriously, it was more productive to work and discuss over Sketch Up or AutoCAD. The AE also mentioned how much of a problem it is to get accustomed to a different control scheme when working in these types of 3D environments, and he personally would hate to jump from working with his mouse in the laptop to trying some touchscreen control in the

phone.

The second problem was just time itself. The concept of comparing the play models to playing with Lego blocks was mentioned several times and prompted the idea that the feature would work very well with a playful attitude, when there was not yet a clear idea of what to do and the group is mostly generating ideas. Once the ideation phase was done, it was important to move faster through the creation of actual material. The AE also remarked that, with the configuration of groups that the course had right now, it would be very difficult for him to recreate that ideation process with every group, which prompted him to just work alone and communicate his ideas in a faster way.

The other students mirrored these thoughts. Being able to use the models to quicky visualise an idea or to communicate a design could work when there was not yet a technical specification. Even with the possibility of integrating technical models into the tool, the conversation simply flowed faster and better by quickly discussing things over their laptops and transmitting information and questions over instant messaging.

The area they thought had the most potential for a feature like the play models, especially if an external render could be integrated with the tool, would be in communications with the client and the final presentation of their work, like with the poster presentation they were working on now. They mentioned that it would be an extra layer of complexity for the presentation but would be an interesting and rather flashy tool to communicate the technical ideas of the project to the client in a way that would offer an advantage over a poster or a written report.

6.4.3 Preliminary Analysis

The work done for the poster presentation represented the biggest instance in the course in which all the elements of collaborative work were present: students had to pool their resources and agree on a solution. Work was interdependent, required planification, communication and coordination. Groups that were having a better time progressing with the project were those that manage to establish a clear line of communication, learned to work with the needs and strengths of their team, were able to take decisions fast and incorporate feedback when received. Groups having problems with the course where those that had a problem looking beyond the individual tasks required of each role, had poor or non-existent channels of communication and were not using the spaces in the classroom to organise and check the status of their work.

So far, the students had interacted with the tools provided by WorkshopAR meant for team management and organization and with the interactions designed to help with communication (annotation and debates) and with the co-creation activities of the project (the play models).

Figure 6.6 shows a simple comparison of how the four groups observed were dealing with the major activities identified at this point of the project. The comparison is based on what was observed and reported by the students and their direct responses to how they would use *WorkshopAR* in the same circumstances they were at that moment.

It was not possible to gather enough data from Team A to build a clear picture of how they would have used WorkshopAR during the first encounter activities or during their work for the poster delivery. The main idea that was possible to extract from Team A was the importance that the flow of information had in the project and the challenges experimented

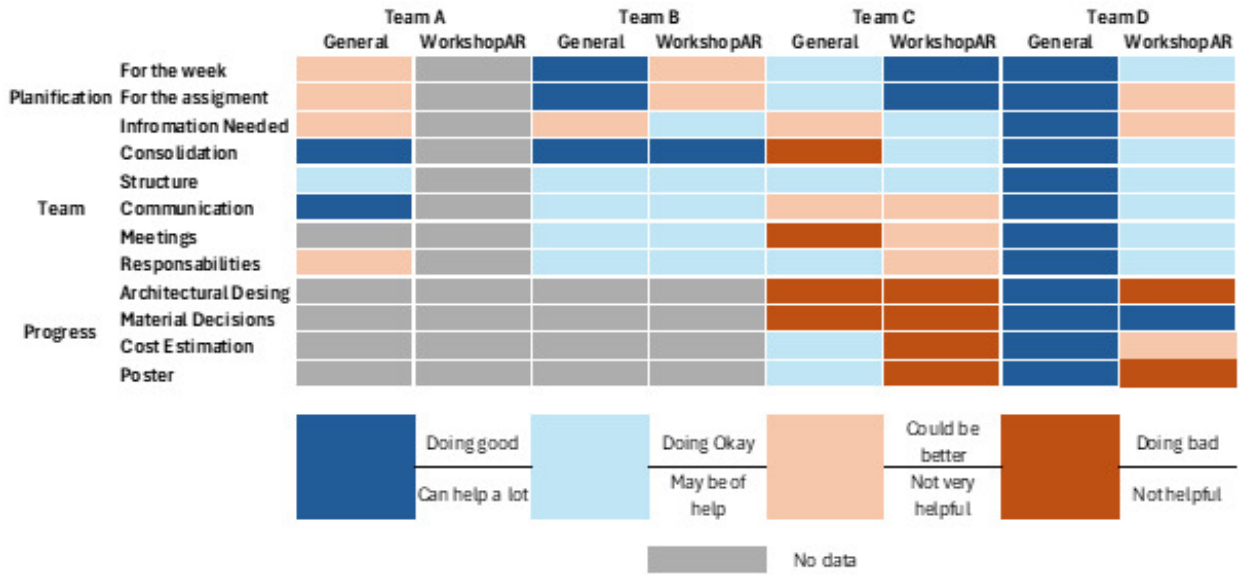


Figure 6.6: Comparison Between the Reported State of a Group's Work and the Possible Benefits of the Use of *WorkshopAR*

by the students to overcome it. Paired with the observations of the other teams, that division between groups properly managing the information issue and those who could not was evident.

The first response of the students to *WorkshopAR* was to that challenge of consolidating the group. The most consistent positive association was with management activities, like organising the information of the participants and giving guidance on how to structure the activities of the day. Negative responses in this topic from Team C and D derived directly from their situation during the observations. Team C had basically no team to manage, and Team D successfully formulated a working structure for their group, making a direct use of the tools provided by *WorkshopAR* less useful.

In both scenarios, *WorkshopAR* only provided support for communication inside the team, and could not incorporate roles like the TA, the lecturers or other students hoping between groups gathering information. This situation did not escape the design phase of the tool but was cut off in consideration of the scope of the research and the initial set up of the observation process proposed. Interesting instances of collaboration were observed during these interactions, and this can be an interesting point of expansion and refinement of the research in future work.

The response to the play models also made it clear that adjustments were needed. The major issues most students had with the tool were not much related with how it worked, but how it could be incorporated in the activities they were focusing on. Team C was working on cost estimations since no other member of the group was with them, therefore they found more use of the annotations and debates to organize ideas and manage discussion. Team D was in a better position to see the possible benefits of the play models, but the tool did not offer much value at the stage their architectural design was.

For the next step in the execution of the case study and the development process running in parallel with *WorkshopAR*, there were already several objectives in mind:

1. Refine the interactions with the play models and identify how to integrate the activity better with the workflow of the students.

2. Explore more the annotations and debate feature since they gathered the most attention from the students.

3. Refine the way structure was presented to the students and allow for more flexible configurations.

It was starting to be apparent that students were not so open to a work application, since they already had identified and integrated to their workflow all the tools they considered necessary for their work. What resonated the most with them was the idea of a social space, and away to deal better with the issues of communication that were taking place inside the classroom, and not so much outside of it.

6.5 Weeks 10 to 13: Interim Client Report

The final stretch before the end of the semester was focused on the interim client report, a document that each role had to submit to the client, summarising the most important decisions taken by the group and the progress so far in the development of the project.

Although at the end, the poster presentation was an individual task, it needed an important collaborative effort to build the proposal and fulfil all the requirements in the marking criteria. In contrast, the report had minimal collaborative elements, and the situation was quickly reflected in the way the groups approached their work in comparison to previous weeks.

There was a substantial clash with the objectives proposed for the intervention during this last section of the semester. It was not as easy to observe the interactions between students in the classroom nor the initial intended use of the play models function, but it was not a complete loss.

The extra time acquired was used to extend the development time planned for the second iteration, and with the help of some of the students who were still consistently showing up to the classroom sessions, it was possible to discover other scenarios in which *WorkshopAR* could integrate better with the work of the students.

6.5.1 General Observations

The official work for the course was extended to thirteen weeks so that the students struggling to complete the requirements of the project had extra time to gather information and organise their work. The big division between groups got more pronounced in this period: groups trying to catch up and groups that all but finished the work needed for the semester and were not really in need of the space during the classroom session.

The general observations for these weeks were few and easy to summarise: the groups that were not trying to finish all the missing work for the poster assignment were working on finishing or polishing the interim report. Team D helped a lot during this time, as they were far ahead in their work and found it useful to keep coming to the classroom to finish all their planned tasks and then have the rest of the week for themselves. The classroom was less

chaotic, and work was less stressful in comparison to the previous weeks. The *work session* was also a huge contrast with the buzzing activities observed before. There was minimal communication between the students, mostly idle chat, while they were all focused on their own work and gathered as a group at the same table out of routine.

The idea of the interim report, as explained in the LMS, was to gather the information and feedback received from the poster presentation and work in a progress report to the client as a group, and then extract the sections relevant for each role for the individual submissions.

The group confessed that they were not working like that at all. Although they were all working on the report, each student had their own objectives and was moving at their own pace. They had sought feedback from one another a couple of times, but they were mostly working alone. The main reason to keep coming to the classroom was to have easy access to the lecturers if needed, and they did talk with the TA team a couple of times during the observation, mostly seeking quick feedback on the current state of the report.

The group also helped in identifying why the collaborative work had diminished so much. The biggest source of information for the group was now the poster; they just needed to refer to each individual presentation if they needed data about any of the work done by each role. The other big input for the activity was the feedback given by the teaching staff during the presentations in weeks eight and nine, which was also gathered individually. The group analysed that they had worked very well for the poster presentation and the results obtained were very good, so they felt confident they could work individually to finish the report.

6.5.2 Intervention with WorkshopAR

Team D offered their participation for two different observations. Both had the objective of evaluating more scenarios for the play models and to explore ways to integrate the function better with the work of the course. Since Team D was already familiar with *WorkshopAR* and with the general objective of the research, it was useful to hear ideas from the group about what could be changed, improved, or added to *WorkshopAR*. More than ideas, they identified two key issues that they considered were making it hard to integrate *WorkshopAR* with their work:

- They would need to juggle work on the computer and on the phone. It was good to have access to the *digital room* created in AR, but they would have to constantly leap from the phone to the computer, and that was not practical.
- It was odd to them that there was so much emphasis on working with their phone. Some of them were actively trying to reduce their screen time and the classroom sessions were an ideal place to leave the phone aside and focus on work. Using the phone as the main tool for working with the group felt in opposition of what they were trying to achieve.

Team D ran through the main functionalities of *WorkshopAR* again, from the room configuration to quick mock-up interactions with the play models, the annotations and the debate features, these last two in a more complete state by now, which allowed for better feedback about the user experience.

Several of the points that had already been observed previously were reiterated: the student acting as host acquired the responsibility of leading the activity despite not really

having more responsibilities after the configuration, and the interface of the debate tool was prompting the students to propose more elements than the ones needed for the debates. Issues with the technical aspects of the implementation were also mentioned, like a constant drift of the AR visualisation whenever focus of the marker was lost.

When asked which of all the functionalities they considered offered the most value for their group work, the answer was unanimous: the debate tool was easy and quick to use, and they were resonating a lot with the emoji-like visuals used to represent the answers without the need of text (see Section 5.2.3).

6.5.3 Preliminary Analysis

There was a sharp contrast between the work done for the poster presentation and the interim report. The teaching staff commented that it was not exactly the intended outcome. The instructions did ask for a first version of the report to be worked on collaboratively, but the reality was that there was no need for that, since all the resources were available to each student individually. The situation exemplified very well that collaborative work was not a natural occurrence, and it had to be meticulously designed. The teaching staff was very satisfied with the results obtained for the poster presentation, and the observations did corroborate interesting instances of collaborative work and collaborative learning, as they had been described in previous sections.

For *WorkshopAR* and the overall intervention in collaborative learning, it was also possible to line up some interesting preliminary results, either positive, negative or in need of work for the next semester.

Two main positive outcomes so far appeared in the work with students:

- The structure promoted by *WorkshopAR* was helping the students to be more conscious of how they were managing their activities as a group. The students started to frame their work in terms of goals, tasks and responsibilities once introduced to those concepts.

- The visual elements used to augment the space used for work were creating the intended results of group cohesion and added meaning. Students recognised the value of *"starting the work session* by joining the *digital room*, and it was possible to observe students giving extra meaning to spaces like walls or tables using annotations, or conveying extra meaning to a conversation using the debates and the visual elements added to the responses.

WorkshopAR also promoted negative elements. Some of those are especially relevant because they were not only observed but also explicitly mentioned by the students:

- It was uncomfortable and very impractical to keep jumping from the computer to the phone, and the tool was not built to be constantly put in standby. A lot of time was used just setting up *WorkshopAR* repeatedly.

- Students preferred quick and easy interactions between them. Long conversations and long debates were simply not happening.

- The project was big and had many moving parts. A lot of work was done during the classroom sessions, but there was also a lot of collaborative effort happening outside. There was no way to coordinate the things done outside *WorkshopAR* with the things done within it.

Finally, there were aspects of the current experience that could be iterated on during the semester break to get a better response from the students or to explore more the collaborative learning process that were not taken into consideration during the design phase:

- Expand the annotations and debate functionalities to promote more activities of short and quick interactions between students during the work sessions.
- Create a setting in which the phone was seen as a work tool and not a distraction.
- Means to configure the amount of structure enforced by *WorkshopAR* to accommodate those group that did not need that much guidance or that were already familiar with the workflow promoted by the software.

This analysis helped to organise and focus the work needed during the semester break, to proposed clear objectives for the second iteration of development and to prepare the second round of observations.

6.6 Weeks 14 to 20: Second Semester Observations

This last section of observations will encompass all the work done during the second semester. The recount of activities for these last are more general and don't cover the entire work of the students in the course due to a couple of factors:

- The activities proposed for the groups were the same as in the previous semester, a poster, and a final client report. This time the aim was to refine the design of the project.
- Of the twelve weeks of work for the semester, only six were observed, those dedicated to the work on the poster presentation since it was the activity that demonstrated the most collaborative work the previous semester.
- The observations were even more focused, with the specific objective of evaluating the changes made to the physical disposition of the tool and to the annotations and debate features.

Besides some substantial changes made to the presentation of information in the LMS, the structure of the course was the same, the groups were firmly established by then and the overall objective of the project was clear. The assignments were also the same, a poster presentation and a final report, this time focused on refining the work done in the previous semester and to present the final version of the solution.

6.6.1 General Observations

Like in Semester 1, Team D provided most helpful feedback during the observations in the second semester. It was valuable to have the opportunity to test most of the new approaches of *WorkshopAR* with them since they had experience with the previous versions of the tool and were familiar with the context of the research.

The distinction between groups that had formed during the previous semester and that was described in Section 6.6.1 was also noticeable during the second semester. Some groups, like Team D, had a good head start from the previous semester and their work focused more on refining the project. On the other hand, other groups had to reform, keep working with less team members or start with a new proposal, creating a more intense scenario for their work.

Team D obtained very good results in the previous semester, and they were a bit complacent with their work. The general observations described for weeks ten to thirteen remained present throughout the new semester: collaboration was minimal because the intensity of the work was also down, and they kept coming to the classroom because it was the best place to advance in their work throughout the week.

Team E offered an interesting contrast. First, they will be referred as Team E just for simplicity, because the observation took place when several students were working together with the aid of one of the lecturers, but they were not necessarily from the same group. In fact, some members of Team B were present there. They commented that they had a lot of communication problems towards the end of the poster presentation because a lot of the members never showed up for class. At the end, the two members present tried their best to gather as much information as possible to later coordinate with the rest of the group via instant messaging. It was not ideal, but it was the process that worked best for them.

As with Team D, the work in Tem E consisted mostly of individual efforts using computers and the direct help of the lecturer, who was giving feedback to the students and making some conversation to help them think more critically about the tasks they were doing.

Although information was flowing better between the students, the work observed turned out more individual since the groups were mostly linked by the architectural design they were working on in the previous semester rather than by the need for collaboration. There was not much value any more to be present in the classroom session, therefore, assistance was very low.

The situation was similar to what was observed during the last weeks of the previous semester, and for the activities with WorkshopAR, there were less opportunities for more extensive discussions as the ones found previously, but it was possible to gather some interesting responses to the changes made to the approach with the tool, as detailed in the next section.

6.6.2 Intervention with WorkshopAR

The observations with Teams D and E had the same objectives in mind: test the clamp arm set up and the adjustments to the social communication tools added to the annotations and debate tools. Other features of *WorkshopAR* also undertook some adjustments that had been tested more thoroughly during the unstructured testing stages, and it was considered more

interesting for the observations to focus on the changes mentioned initially.

The process followed for Team E was slightly different since they needed a quick tour of *WorkshopAR*. Their general response to those initial features did not add much to what had already been documented in previous sections. Team D recognised the changes done to the original proposal, which also included an updated UI look, so their response was very positive in general and highlighted the fact that the tool was evolving based on what had been discussed previously with them.

Setup with the Articulated Clamp Arms

The idea with the clamp arms was aimed at exploring how the phone could be used in the classroom in a way that was seen as an enhancement and not a distraction. Studies analysing this same problem in other contexts and through different perspectives can be found in Consoli et al. (2025), Fälth and Selenius (2024), Flanigan et al. (2023), and Forsling (2023). The idea was also strongly linked to the way students had been observed to work for the Industry Project course, setting up a table with the equipment they were using to work during the classroom session. They had access to the teaching staff and to all the other activities in the classroom without the need to take down the setup.

Section 5.2.4 provides more details of the implementation of this idea and the interaction design done around it. During the observations, some problems were found with the setup, mostly at the usability level:

- The setup was a very intensive process, and it required access to a lot of resources like the clamp arms, a table and enough time in the work session for the whole ordeal to be worth of the time expended.
- It eliminated the flexibility of creating a room in any space the group found available, running in contradiction with one of the core design principles of the tool.
- It gave too much emphasis to the phone, which was also in contradiction with the initial premise of the solution.

Team E offered the most positive remarks to the idea, comparing the setup to a streaming rig used to create content in a professional way. That comment prompted a conversation about having access to a space that already provided the setup and that could be used to work in a hot desk fashion, like how some creative labs work in faculties like design or art. The setup could be adapted to be a laboratory for digital collaborative work, offering all the resources needed for the students. It was an interesting comparison that came from conversations with the students, and although it would run in contradiction with the premise of a flexible room for the group and the BYOD philosophy, it could be the basis for a future exploration of the idea.

Team D was more critical of the setup with the clamp arms. In was possible to run the whole configuration process of WorkshopAR with the team and retest the functionalities while using the setup. The most telling observation was that the students quickly removed the phone from the clamps to make the process easier, giving a strong impression that the idea was not a practical solution.

The clamp arms setup tried to give the interactions with the phone a better position inside the activity, more in line with the working mindset the group wanted to follow. Some students saw the potential in the setup to create that working space, but others still felt that they were playing with their phones. A third group felt annoyed that they were losing access to their phone and using it only for work, and not for other activities, which was in direct contrast to all the other attitudes seen before.

This is a situation in which it is difficult to find a solution that accommodates every perspective, and with any proposal, at the end someone will feel alienated. A stationary setup using non-smartphone mobile platform like tablets could create an interesting solution using AR. Projects using this idea to provide an assistance tool in diverse scenarios can be found in Barbieri et al. (2025) and Ma et al. (2026).

Communication Features and Emotes

Based on the comments and reactions of the students, as well as the participants in the unstructured tests, it was identified that the visuals used to quickly convey information in the debate feature could be used by the students in other contexts, creating more freedom and flexibility in the communication features provided by *WorkshopAR*.

The same type of visuals was implemented in the annotation feature, and the unstructured configuration of the debates also allowed for a free flow of conversations that had access to the visuals meant initially for the responses. Originally, the visuals were used to convey information like yes, no or an option in a multi-option question, but students commented that the responses reminded them of the emojis use in text messages, prompting the idea of using *floating* emojis that could add some context or connotation to a conversation.

The idea was tested in two different scenarios. The first one offered a more conventional activity using highly structured questions in the debate tool and waiting for the participants to provide answers through the tool. The idea was to provide an opportunity for a real discussion to take place among the students, but neither Team D nor E engaged significantly in that way. They interacted briefly only through mock-up questions about the progress of the project or technical aspects of the design without much substance in them.

Observed behaviours in both teams were similar: some students preferred more textual answers while other chose the more visual version, with no strong observable tendency for one option or the other. The graphical cues offered by the app like colours and symbols were easily understood, students could read the information quickly and react to the information communicated by their peers without a problem. Technically it was a sound implementation, but it was not possible to observe any substantial behaviour with the current approach to work that both teams had during the classroom session.

The second scenario was more open and used the unstructured version of the debate function to let the students openly talk and discuss things during the work session. This setup prompted more conversation than the previous scenario, students tested more the unstructured questions and started to be more playful with the activity, proposing question unrelated to the project and more humorous uses of the emotes, taking advantage of the visuals provided to give a stronger emotional context to whatever was the centre of discussion.

Team D found the free conversation very enticing, and it was interesting to see, after the activity itself was already over, that the group was coming back to the tool to show their

reactions to a comment or a situation during their work. Most of those conversations were unrelated to the project and played more for fun than for actual communication, but it was telling that the tool was used to properly convey meaning and was able to be integrated naturally into the actions of the students.

Team E, on the other hand, did not show any instance of such natural use of the tool, but in general they were not speaking between them at all. The mood of the session was more relaxed with Team D than with Team E, which also promoted a better environment for casual conversation and a more playful attitude, which seemed to be the better context for the use of the tool.

6.6.3 Preliminary Analysis

These weeks represented the end of the observation stage, and based on the previous preliminary processes of analysis, it is possible to summarise some of the most important themes extracted from the observations gathered:

- The dynamics observer for any group would determine if they preferred a more structured approach to teamwork, needing more guidance from the available teaching staff and using more the tools provided by *WorkshopAR* to help them in the first steps of consolidating the group.
- Better established groups would prefer a more flexible approach to the activity, relying in the mechanisms they themselves had built and finding any external intervention, either the lecturers or the use of *WorkshopAR*, more as a hindrance than an actual help.
- In either case, the need for structure would be greater at the beginning and would fade towards the end of the project, either because the mechanisms for groupwork are clear or because the tool is not helping in creating of reinforcing those mechanisms.
- Digital tools need to be able to adapt and connect to the environment they live in. All students have their own set of tools and favourite channels of communication than often collide with any other alternative or even with the official channels proposed by the course.
- Visual communication is a powerful tool to promote all sort of behaviours. Activities related to the organisation of ideas, communication between peers and teaching staff, backlog of activities and the contextual meaning of a conversation were all using some form of visual aide, and students resonated the most with *WorkshopAR* when they found those visual elements to interact with.

The involvement of *WorkshopAR* in these scenarios had its ups and lows. A summary of the whole experience could be as follows: *WorkshopAR* succeeded at initiating discussions and reflections around the dynamics a team could be using to manage their collaborative effort, both failed at integrating into the actual mechanisms that the students implemented to fulfil their tasks. *WorkshopAR* was a good conversation starter, but it needs more iterations to offer a real implementation.

The following sections will complement the points previously explained by painting a more specific view of both the teaching staff and the students of how the course developed and how different key aspects of collaborative work and collaborative learning were perceived, and will be compared to the behaviours observed around the use of *WorkshopAR* to better construct a conclusion and identify the lessons that could be extracted from the case study.

6.7 Analysis of Students' Observations and Responses

A set of unstructured interviews was used to complement the data obtained through the development of the case study. These interviews had the objective to gather more information about how each student perceived the way their team implemented collaborative techniques in their work, if there were explicit mechanisms in the group to manage teamwork, how effective they were, and what tools were used to support that collaboration.

Observational data indicated that students struggled the most with communication issues, having problems at the moment of gathering information about the project from the teaching staff or about the design proposal from the AE or the CE. It was also observed that those groups that were able to build a stable workflow navigated the requirements of the project very fast, managing to achieve an early finish towards the poster presentations and relying on more individual polish of the available information towards the end of the project.

WorkshopAR worked best when the students were struggling to create a structured plan with the team but was seen as a distraction when there was a clear methodology, and the students just wanted just to achieve a maximum of progress during the classroom sessions.

Interactions between members of the group were quick and to the point. Sometimes bigger discussions and decisions were needed, and *WorkshopAR* had a more substantial role to fulfil on these occasions, but for most conversations, the extra configuration and structure proposed for the app was too much in comparison to what the actual conversation needed. Big conversations and discussions in the group also often included the lecturer or a TA, which were not integrated into the design of *WorkshopAR*.

The information gathered from the interviews was meant to give more details about these observations or to identify situations that were not evident earlier. It was of especial interest to try and gather information about the collaborative work done outside of the classroom, if any, and the development of groups that were not consistently participating in the weekly sessions.

Regrettably, of the approximately eighty students taking part in the course, only eleven participated in the interviews. The sample also probably underrepresents that population of interest of the students not actively participating in class. Nevertheless, interesting themes emerged from the gathered information that aligned with the themes coded during the observation phase and gave a bit more of context to some of the problems identified with information flow and the structure of the teams. Appendix C shows the questionnaire used for the interviews.

6.7.1 Team Management

The first three questions asked the student to identify how the team organised itself, if there were explicit or inferred rules the group was using to coordinate the work and if any roles or common habits kept appearing in meetings or work sessions.

Question 1 asked about the rules or procedures that naturally emerged in the group during the first weeks of team consolidation. Students did identify and listed strict rules that the group was adhering to, often related to timely deliveries and weekly meetings. When it was not possible to identify a concrete set of rules, it was because the group reported having a good established communication and were in no need to enforce specific rules. On the other hand, few students never talked about any form of rules in the group and experienced a bad organisation and development of the project because of that.

Question 2 asked when those rules were established and how the group participated formulating those rules. Most students reported simply following a strong lead (or reported being that strong lead). It was surprising to find that several students saw in the AE and their flow of work the ruleset to follow within the group. This situation echoed what was reported in question 3, were seven out of the eleven students saw themselves as the leader of the group, associating this role to assigning tasks and proposing workplans.

All the students saw themselves working in a sub team inside their overall assigned group, something that was not observed during the classroom sessions. Smaller groups of roles under a common AE would group together for work (all the CE or all the QS for example), and a lot of students would see themselves leading these smaller groups, while the AE led the bigger overlapping team. *WorkshopAR* did not contemplate this behaviour and was not supporting this flow of information among smaller groups, which was a missed opportunity.

6.7.2 Team Management

Questions 4 and 5 were meant to gather anecdotal data about good and bad instances of collaboration between the groups with the objective of identifying recurrent themes, common practices and tools, digital or not, that were present during those episodes. Positive experiences were always characterised by effective communication, almost entirely asynchronous, and used to coordinate the team, ask for feedback or check on the progress of the group. Some specific tools were mentioned as positive ways of communication, Instagram and Teams mentioned most frequently, but the idea was often kept general, indicating that several channels of communication contributed to the positive perception.

In contrast, negative experiences always alluded to lack of communication, and it was interesting to see that most students reflected that their biggest issues were to not use the face-to-face spaces for work properly. Even when consistent asynchronous communication was present, students felt that the lack of a presential collaborative work caused them to not produce good or better results.

6.7.3 Learning Mechanisms

When asked in question 6 what mechanisms they used to solve the issues identified, it was concerning to see that the students simply did not have the tools to deal with those situations,

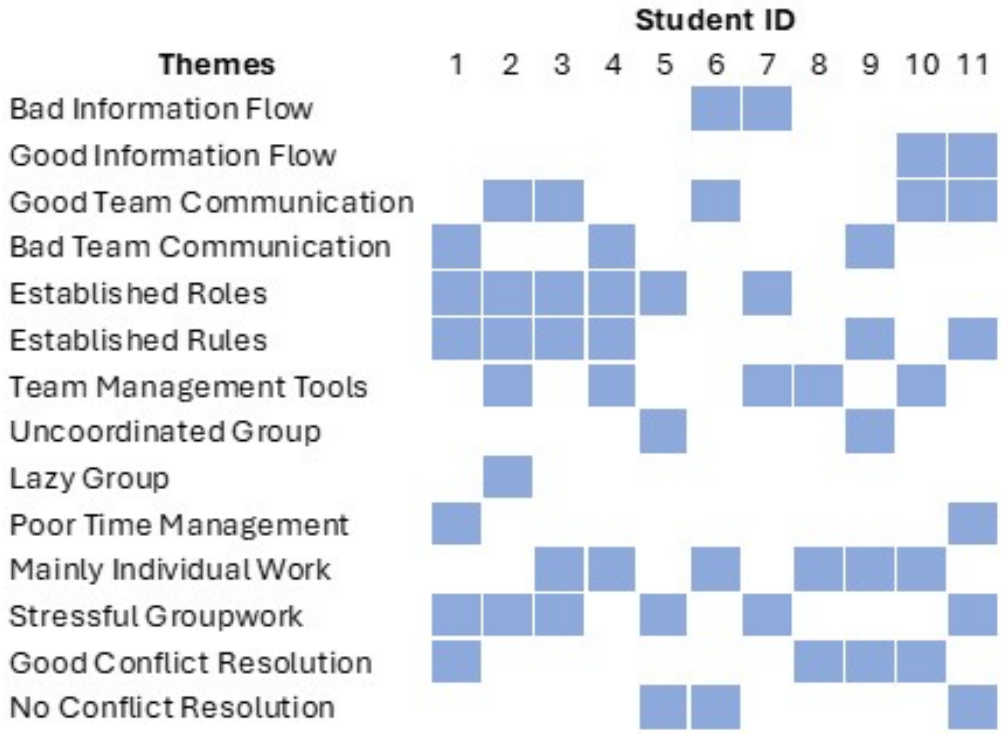


Figure 6.7: Distribution of Themes in the Interviewed Students

and they were not accessing the resources given to them in the course to start working towards a solution. It was quite telling that one of the students preferred to use ChatGPT to get ideas on how to solve the issues with communication instead of approaching the resources in the course.

The responses to question 7 reflected this issue and how unprepared the students felt to deal with the requirements of a larger scale team project. Eight of the eleven students interviewed would have preferred to do the work individually or saw the necessity of groupwork only because the size of the project was too big for an individual. Most of them reported feeling too much stress due to conflicts within the group and being overwhelmed by the amount of energy needed for team management.

Figure 6.7 shows the distribution of the main themes identified among the students that participated in the interviews. Most students reported to follow some form of rules or role allocation, but in general they did not appear to approach collaborative work in a systematic way. This can also be seen in the prevalence of reporting a preference for individual work and the lack of explicit tools for team management.

The observations of the use of *WorkshopAR* also showed that the students were able to quickly incorporate simple strategies to improve their teamwork, they just needed the space to properly identify those tools and incorporate them in their work.

It is also interesting to notice that the students reported a preference of asynchronous communication technologies to support the coordination and general management of the group. Groups that succeed in establishing good communications practices did so using tools like Instagram and WhatsApp, while those groups that were having problems with communication

reported lack of consisted responses and the misuses of the selected communication channels. This perfectly reflects what was seen with the use of *WorkshopAR*, where the tools for team administration were glossed over and seen as too time consuming, but those supporting face-to-face conversation and a flexible interchange of communication were seen in a more positive way and saw more recurrent use.

6.8 Analysis of Teaching Staff's Observations and Responses

Like the interviews for students, the interviews done with the teaching staff had the objective of complementing the information found during the observation process. The time spend with the groups was focused mostly on identifying and describing the relationships formed inside them and the mechanisms used in their collaborative work, having in mind that initially the observations were going to take place outside the classroom. With the changes in the protocol, the importance of the teaching staff came into consideration when analysing the work done by the groups, although the development of WorkshopAR did not contemplate the role of the lecturer. The observations showed evidence of how the students integrated the lecturers and the TA team as part of the resources needed for the project and how the teaching staff influenced in different ways the dynamics of the group, either in their role of clients or as the final arbiter in the resolution of conflicts.

The interviews helped in understanding the point of view of the teaching staff, how they were navigating the challenges of a collaborative design and their perspectives on the work done by the students, the issues they were paying attention to the most and their opinions on the results obtained so far with the intervention using *WorkshopAR*. Three different members of the teaching staff were directly interviewed, two TAs and one of the members of the task team. Appendix C shows the questionnaire used for the interviews.

6.8.1 Effective Collaboration

Questions 1 and 2 were concerned with assessment, and what the teaching staff was expecting to observe as good or bad collaboration. Teamwork itself was not part of the marking criteria, but the quality of the work done was expected to reflect the effort of a well-coordinated team. For the three staff members interviewed, that could be evidenced by:

- An established and consistent protocol for communication.
- A joint effort to participate in the activities of the classroom.
- Balanced results, showing the strengths of each student.

Communication was again the main point of consideration. The teaching staff added another dimension that the students did not talk about, and it was consistency. It was not enough to have established channels of communication or being able to be in contact one time with one student. Successful groups showed that they could consistently get information,

transmit it, and discuss it. This was evident in work their work if they showed a clear group effort and not only a repetition of the work done by the AE.

Question 3 then asked what the teaching staff could do to promote a better collaboration in the groups, managing that process of learning to collaborate. General guidance seems to be the most common approach, offering the students counselling and feedback on their work. An interesting proposal was to let the students fail, to not intervene that much when issues related to teamwork were happening because learning to deal with those problems was part of the process too.

WorkshopAR acted here as an interesting asset for the students, and the teaching staff considered that any tool that could be used to organise information and promote structured dialogue in the students is valuable. The problem with the approach with *WorkshopAR*, which also was evidenced with the initial approach with the LMS, is that they were used the most by the groups that needed it the least. The problem for most groups was not a limited access to tools that could help them, it was a general reticence and failure to use them.

6.8.2 Teaching Collaboration

Question 4 moved the focus from the students to the course itself and asked the staff if they though that the collaborative approach used was benefiting the learning objectives proposed. The common response was that the structure of the course had a lot of potential but required way more polish. As with the restructure of the LMS, several more aspects of the course could be put through the design board again, with the objective of letting the students deal with issues coming from their teamwork and not from the course.

The result gathered from the interviews with students also highlighted an ingrained reluctance of many people to work in teams. Question 5 asked for personal views on how to deal with students with this attitude, and it came to showing the value of collaboration. Several ideas were discussed about how this value could materialise for the students:

- Projects and activities that resemble professional work.
- Rewarding the work done and not only the results.
- Sharing resources that could be transferable to other instances in the university.

When *WorkshopAR* was mentioned as part of the discussion, it was recognised as a very useful tool to learn that structure and help to give a name to concepts that many times were executed without a clear reasoning behind them (prioritising tasks and adjusting the scope of the project were used as examples). But it was also remarked that the tool had to respect the time of the students, reinforcing that idea that any friction should come from the work of the students themselves and not from the tools used to help them. This again mirrored the observations of students using the tool more at the beginning of the project and less when the group was already consolidated.

Finally, questions 6 and 7 touched on the subject of administrative burden when implementing collaborative approaches, a subject also explored in studies like Hendry et al. (2003), Kaendler et al. (2015), and Le et al. (2018). Answers here were brief. It was evident that Industry Project was a complex course with a lot of moving parts, but fortunately,

the team behind the course was showing a good example of collaborative work by dealing with a complex task, analysing the situation and proposing changes to evolved and improve the experience for the students. If there was a noticeable challenge for the team in the implementation of a collaborative approach, it was the process of effectively transmitting to the students the importance of developing these skills.

Figure 6.8 shows the distribution of themes found in the interviews. The teaching staff agree on the importance of establishing early proper channels of communication, and how the time invested in good team management and synergy is reflected in the results shown by the group. The staff also showed varied ideas about how to teach collaboration and how to use it in the classroom. There is more consensus on the positive results that a good collaborative approach creates than in how to properly guide students to create that effective teamwork. This is an interesting issue to explore and discuss more in future work.

6.9 Conclusions

The Industry Project course provided a case study in CL where students had the opportunity to develop the skills needed to implement an effective teamwork process to build the knowledge needed for the course.

The implementation of the software *WorkshopAR* explored a TEL intervention that used AR technologies to support and guide the students in the development of collaborative skills and created a learning space based on collaboration in which the students could apply those skills to work towards the learning goals of the course.

The data gathered through the analysis of the case study can be used to evaluate the impact that WorkshopAR had in the students that interacted with it. This analysis can be guided by the objectives proposed in Section 4.1, which established the framework that was going to be used for the analysis of the observational data.

OO1 stated the use of *WorkshopAR* to aid with activities of team management, as well to promote effective structures for planning a work session. The latter was observed to be the functionality best suited for the work done by the students in the classroom, but its use was not consistent. Students found the tool useful when the structure was first introduced to them during the consolidation of the group but found it too restrictive when they had later developed more the relationships and mechanisms of the team.

OO2 was first focused on the decision-making process of the group, but it was extended to the visualisation of any form of information in the physical space. The approach taken with *WorkshopAR* pivoted the most during the development of the case study based on the reactions of the students and the feedback provided in this scenario. It was observed that the tool was providing positive and interesting channels of communication during the execution of the work sessions. These channels allowed the students to not only have a visual representation of the information flowing in the conversation, they could also represent other aspects of the context like their feelings and thoughts, enriching the conversation and creating more avenues of expression.

OO3 proposed the augmentation of space and how *WorkshopAR* could provide interactions designed to create a sense of shared presence of the digital information used during the work session. Using AR, the software created visualisation and interaction points for the digital

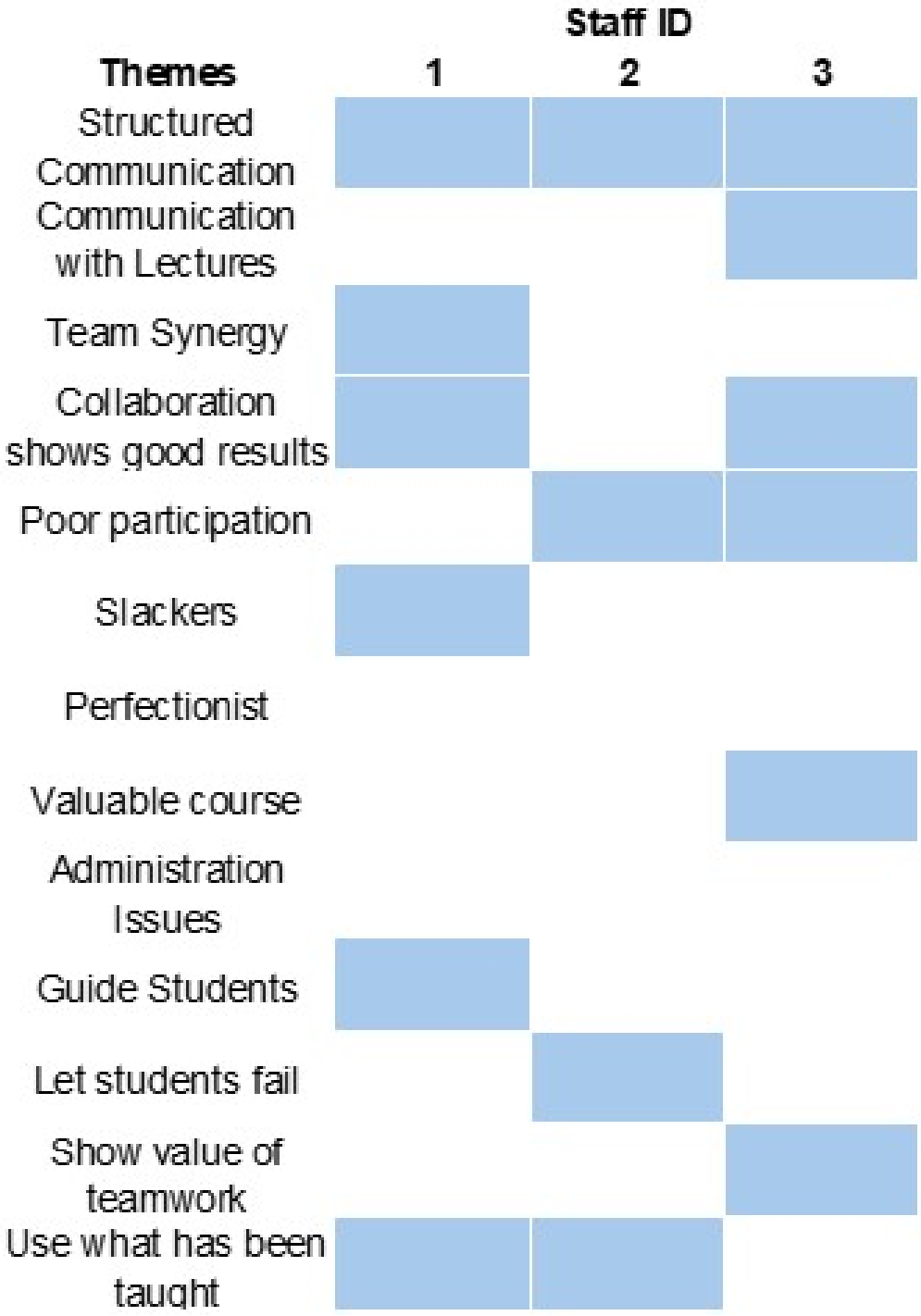


Figure 6.8: Distribution of Themes in the Staff Interviews

profile of the students, the space used for work, and the decisions taken for the planned activities. The students found interesting ways of giving additional meanings to the working space using digital information, but the use of *WorkshopAR* clashed in the end with all the other tools used by the students to complete their work, as well as with the commitment in time and effort needed to fully use *WorkshopAR*.

The development of this case study showed different positive and negative behaviours around these three use scenarios which together form an interesting picture of how the technology integrated into the learning development of the course. It can be summarised that *WorkshopAR*:

- Offered the opportunity to learn and apply effective structures for collaborative work
- Created an inconvenient layer of configuration for those students that already had developed a clear workflow in their groups, so it had to offer an alternative and more flexible version of the available tools to keep providing the same perceived value.
- It failed to create an enticing augmentation for the design process needed for the project but offered interesting tools to augment the physical space with information and the communication process with extra layers of meaning.

To complement this analysis, the observation objectives can also be evaluated alongside the learning goals proposed in Section 3.3.1 to determine, beside the positive and negative behaviours observed, if the intended learning process behind the development of the tool was achieved.

LO1. *WorkshopAR* introduced and implemented the ideas of a *work session*, goals and assigned tasks. Those students struggling to create effective teamwork adopted these ideas and started discussing ways to better implement them in their work. Those students having better results were also using the same ideas, but they were discussing and evaluating them using other tools and in a more asynchronous conversation with their team.

LO2. Students did not show complex instances of collaboration to create the material needed for the project, neither within *WorkshopAR* nor outside it. The design of the course encouraged high levels of coordination and communication, but not of co-creation. Students preferred to work individually and using the tools with which they were already familiar.

LO3. Students excelled at providing solutions for the biggest challenge of the course in the acquisition, evaluation, and organisation of information. Those students that succeeded in this objective created various channels of communication, synchronous and asynchronous in nature, one of which was *WorkshopAR*, providing an interesting environment to support face-to-face communication that was casual, exploratory, and dynamic in nature.

LO4. There was not enough evidence for a conclusive assessment of this objective. There was no observed instance of students reflecting on their work or creating any form of self-assessment. The evaluation process of the course asked students to create these types of self-reflection, but that work failed to show in the observations. It could be speculated that the process could have benefitted from the same communication tools that were used in other types of conversations and discussion, especially those offered in the structured version of the debate tool.

It was gratifying to see that the objectives of the research mirrored those of the course, and that the students were achieving their goals by taking advantage of the resources given to them. The students were analysing and executing the requirements of the project using all the tools they had at hand, *WorkshopAR* included.

WorkshopAR, as a prototype, presented a positive performance among the students. It created opportunities for discussion and positive changes in behaviour, and when the engagement failed to show or negative changes were observed, it was possible to pivot the design and propose an alternative scenario. A good overall analysis of what was observed with the tool in the context of the learning objectives proposed can be summarised as:

- It provided the flexibility to be used at different stages of the project development and with different group profiles.
- It succeeded at using the visual and interaction capability of AR to augment the working space and the communication process of the students.
- It failed to properly integrate with the co-creation process taking place in the course.
- It promoted discussion about how to integrate mobile technologies in the classroom and showed the diversity of attitudes that university students adopt towards this subject.

The implementation of *WorkshopAR* in the Industry Project course was a positive and satisfactory experience overall that provided different points of view and opportunities for analysis that will allow a final reflection towards building answers to the research questions, which will be the objective of the next and final chapter.

Chapter 7

Conclusions

This doctoral research explored the use of Augmented Reality technologies to create a learning environment based on the principes of Collaborative Learning. Augmented Reality (AR) technologies provide unique characteristics that can be used to promote diverse learning scenarios in which students participate more, report more engagement and develop different dynamics with the learning material. Additionally, Collaborative Learning (CL) approaches use social tools to encourage the students to gradually build the knowledge they need as part of a community and better mirroring the environments and challenges that can be found in real life.

Of the characteristics identified, this project focused on exploring these main attributes that distinguish AR from other platforms and CL from other learning philosophies:

- Digital visuals that incorporate and react to the physical context of the user.
- Interactions with the environment that promote creative approaches to the learning material, exploration and active participation.
- Multiple communication channels that promote constant dialogue and conversation between participants.
- Guidance in identifying and using the skills necessary to create a collaborative effort as part of a group.

This project proposed that combining different characteristics of AR with the connectivity and social tools provided by mobile platforms, it is possible to create a learning space that promoted and facilitated the use of collaboration and teamwork as teaching tools and learning goals. The main objective was to identify how students approached challenges of collaborative learning using digital technologies, and to design a tool based on AR that could promote behaviours that boost or reinforce effective collaboration and the development of teamwork skills.

The approach of the project to fulfil this objective was divided into two parts. First, a software developed using user-centred design that identified core issues about interactions in AR spaces, multiuser experiences using AR, and the challenges associated to develop software for learning support. The second part was the analysis of a case study in which AR was used

as a tool to provide support for the objectives of a course that were using a collaborative learning philosophy or developing collaboration as a skill.

WorkshopAR was the prototype software born from these two research parts and was used to test different features that used AR interactions to help students manage a collaborative activity, while supporting the course in teaching basic principles of effective teambuilding and cooperation practices. *WorkshopAR* provided tools for:

- Augmenting the space that a group of students is using to work, providing visuals and interactions to help with team consolidation, team management, planification, progress evaluation, work management, generation of ideas, knowledge management, decision making and participation management.
- Creating a structured approach to teamwork that can be configured to fit the different stages of a project and the different characteristics and goals a group can have.
- Augmented communication for face-to-face interactions, using visuals and interactions to communicate ideas, expand the context of a conversation, provide extra meaning or to explore ideas and be creative.

The design process of *WorkshopAR* identified important challenges in the implementation of AR software and the development of technologies for learning settings. It highlighted the importance of early testing and of adapting a flexible development approach to identify the particularities of a classroom, understand the needs of the target students and adapt to the different profiles that could be found among them. A classroom is never homogeneous and is never static, and the implementation of the software should be able to adapt to these variable characteristics.

The Industry Project course provided an ideal case study to observe a collaborative design. The core objective was to offer the opportunity to experience a project close to a real-life professional setting, encouraging students to develop and test the skills needed for teamwork, communication, planning and constant self-reflection.

WorkshopAR was integrated into the course as part of the repository of resources available to the students to help them manage the face-to-face collaborative activities present in the classroom sessions. The students found opportunities to use *WorkshopAR* by:

- Using the structure provided by the tool at convenience, analysing the current state of their project, the objectives set up for their work, and the disposition of the current participants.
- Using the space and resources available in the current context to propose ideas, promote discussions and take decisions.
- Maintaining constant communication with their teammates, not only transmitting information but also contextual meaning.

The development of the case study showed the importance of giving the students the space to create collaborative skills in an organic way but also offering guidance when needed, mechanisms to fail safely and opportunities to iterate in the approaches proposed by a group.

WorkshopAR also benefited from this iterative approach, failing to integrate in some aspects of the collaborative process but adapting, incorporating feedback and finally finding an interesting place in other instances of the students' work.

7.1 Research Questions

The research structure of this doctoral project focused on identifying changes in behaviour produced by the AR tool supporting the collaborative work of the students. AR was used in activities related to team management, communication, and decision making.

This thesis proposed six secondary research questions to help build a conclusion for the main objective of the project. The questions were aimed at comparing current approaches and perceptions that students have around collaboration and group-based learning against what AR could offer. The main objective of the software development was to test ideas in which the technology could create a different approach than those already used by the students.

> SQ1: What differences in behaviour can be observed between students collaborating using the AR tool and those that are not?

The use of *WorkshopAR* promoted the most positive behaviours at the beginning of the life cycle of the project, when the students were first consolidating the group, identifying the collaborative mechanisms to be used in the activity and deciding what rules and what roles would be present in the dynamics of their group.

Students were discussing how to organise their group while configuring the *digital room* and identifying elements like the session goal and the assignation of tasks. Even when not directly using *WorkshopAR*, discussions over these elements continued after their introduction, and helped the students with the organisation of their work.

WorkshopAR also created a positive influence with the quick interactions taking place between students during the work session like conversations, planning and decision making. The bulk of the communication of the group was taking place outside of the classroom, and major instances of communication like team organisation and the flow of information needed for the project was mediated by other technologies and taking place using asynchronous methods. *WorkshopAR* gave the students tools to have more dynamic conversations during the classroom time, which was observed to be primarily focused on individual work. The students were using visuals and low structured debates to provide more information about their activities, to add more context to the conversations taking place or simply interacting more between them, which was closer to the initial intent that the teaching staff had for those presential sessions.

The most relevant negative behaviour observed promoted by *WorkshopAR* was an excessive allocation of time in configuration tasks. The work of flow of the groups was interrupted every time that someone wanted to interact with some feature of *WorkshopAR*. If a long time had passed between interactions, the configuration or setup needed was even longer. The work of the students was characterised by medium to long periods of intensive work using a variety of technologies and devices, and *WorkshopAR* failed to integrate well with this environment, disincentivising its use in favour of quicker or more effective means of communication.

SQ2: What differences do the students report in their perception of the activities done in the course between those using the AR tool and those who are not?

One of many requirements for the students to create an effective collaboration during the course was to identify and coordinate all the software tools needed to work and communicate. Students saw *WorkshopAR* as another tool in the repertoire of options at their disposal, and not in contraposition to any other. Some students saw the value in the characteristics of the tool and incorporated it in their work, others preferred to use tools they felt more comfortable with.

Students were able to analyse if the use of *WorkshopAR* was beneficial for a work session or not and setting aside the tool was as valid a decision as trying to use the features of *WorkshopAR*. Rather than changing perceptions or behaving differently with the use of one tool or another, some students incorporated WorkshopAR into their workflow and others not, and both were correct approaches to the situation.

SQ3: How does the collaboration and communication process changes between students using the AR tool and those that are not?

WorkshopAR helped in creating more dynamic and meaningful forms of conversation in the face-to-face setting of the course, as can be evidenced in the observations detailed in Sections 6.4.2 and 6.6.2.

The collaborative design followed by the Industry Project course presented the students with the challenge of understanding the problem of the project and proposing a solution as a group, but relied mostly on individual work for the creation of the deliverables and the assessment of the project, incentivising minimal communication among the members of the group once certain milestones of the project were reached.

The groups that used *WorkshopAR* had more opportunities and resources to communicate between each other during the work session. They discussed more elements about the structure of their work and the current progress of the project and were more open to discuss their individual work with their peers. Those conversations were short but consistent, and their working session were more dynamic.

In contrast, students not using *WorkshopAR* focused more on individual work and the use of personal devices. Communication was mostly with lecturers or with a Teaching Assistant (TA), and the information gathered benefited only their individual work. It did not mean that communication was not present, or that their team management was poor. It meant that those instances of communication were taking place asynchronously and outside the classroom, and the face-to-face session were not being used to their full potential.

SQ4: What differences can be observed in the end results of the course between all the different collaborative approaches observed, especially of those that incorporate the AR tool?

There was no evidence of a relation between the use of *WorkshopAR* and the results achieved by the students. Groups that presented good results were those that organised their resources and established a proper workflow, which sometimes included the use of *WorkshopAR*. Groups that had a better sense of the structure of their work used the tool

more for conversations and debates, while groups that initially struggled more organising themselves used the tool to as an aide and then moved to other objectives. *WorkshopAR* was present in both successful and struggling projects.

The last two secondary questions changed focus to the implementation of the tool itself rather than its role in the case study and required the analysis of what elements of AR were creating the behaviours observed and how they could be better understood and incorporated in future projects.

> SQ5: What elements of a technological intervention using AR create the most impact in changing the behaviours, perceptions or results of the students?

The AR implementation used by *WorkshopAR* succeeded in conveying information about structure and effective team management as well as engaging the students with dynamic and constant communication when other groups were struggling to be more active during the classroom sessions.

In contrast, *WorkshopAR* failed to offer value to the students during activities related to the design and implementation of the proposal for their project. The tool required long configurations and the interactions offered through the play models were only useful during the initial stages of the project.

WorkshopAR was good for proposing and discussing ideas but not to support co-creative collaboration or help in the work needed for the deliverables of the project. The augmentation core of *WorkshopAR* worked better when conveying information in a visual format to the students, but the physical interactions with the digital space were clunky and consumed too much time. In either case, the objective to provide an augmented layer of information to the physical space and to the communication process can be considered positive as shown in Sections 5.2.3 and 6.4.2. Interesting points of discussion for future projects can also be extracted from the analysis of SQ5:

- Data annotation linked both to the physical space and to the *digital room* where participants are interacting. Offer the possibility to save this information, modify it across multiple sessions, and share it with other similar digital spaces.
- More varied methods to support face-to-face communication using visuals and shared interactions, both in structured and unstructured settings.
- Connectivity and synchronisation, not only with the tools provided by mobile platforms (such as photos, contact list and web browsing), but with other tools that are often used in collaboration settings like group chats, repositories of ideas and sketch tools.

> SQ6: What elements of a multi-user AR tool have the most impact in changing the behaviours, perceptions, or results of students collaborating and communicating in a learning scenario?

The possibility of sharing a digital space with the group was at the core of the features proposed by *WorkshopAR*, and it resonated well with the students. The shared space offered tools to represent and give a more tangible presence to the group and allowed the students to

express their personality using the tools present in the User Anchors and the emotes. This type of social activity helped in the dynamics of the groups and promoted a better use of the presential work sessions.

Students were also organised around asynchronous forms of communication and work that WorkshopAR was not supporting, and the students found very limiting that there was no way to coordinate those channels, as both were crucial for their work.

On a similar note, *WorkshopAR* did not incorporate the horizontal interactions between groups that the shared space on the classroom was promoting, nor did it integrate the role of the teaching staff in its workflow, and it was evident that the interaction with WorkshopAR felt disjointed from the rest of the activities because of that.

The secondary research questions offered an overview of what was achieved with the development of WorkshopAR and its implementation in the Industry Project course. AR was used to create a shared environment supporting the activities taking place in the classroom. Observations in Sections 6.3.2 and 6.6.2 show how the technology can help students to better develop the skills necessary for teamwork and collaboration. The participating groups used this tool the most to help them to consolidate their group and to engage in more dynamic processes of conversation. With this information at hand, we can now revisit the main question of this research:

> MQ: How does the behaviour of a group of students changes when using an AR tool designed to aid in the achievement of a learning goal framed in a collaborative learning scenario?

Many of the groups participating in the course showed a bad or poor approach to the face-to-face collaboration setting proposed for the classroom sessions, overfocusing on individual assignments and avoiding almost any form of communication within the group. *WorkshopAR* offered the tools to create more dynamic spaces for conversation and integrated those features better to the workflow proposed by the students, rather than forcing the students to follow a specific structure.

The Industry Project course provides different ways to help the students further develop collaborative skills, but mostly opted to let them explore by themselves the necessities of their group and to find solutions to the hurdles they were encountering. It was satisfactory to see that *WorkshopAR* helped some groups to identify what was lacking in their approach and to continue the conversation of team management using the concepts and mechanisms that *WorkshopAR* provided.

Students were also capable of analysing the resources at their disposals, especially those digital tools needed to complete their work. Students were able to discuss and recognise when *WorkshopAR* was not a good match for their work style or the activities planned for a session and took the decision to explore alternatives that better suited them as a group.

Students disliked the long configuration process required for many of the features of *WorkshopAR* and tried to explore alternatives to either create a more complex working station using the smartphone as a basis, or dedicating more time to the activities mediated by *WorkshopAR* to justify the time invested in configuration. Neither of these approaches related well with the original design of the tool or with the workflow proposed by the course and was affecting the time allocation that students had to manage during the classroom sessions in a negative way.

In conclusion, it was possible to observe both positive and negative behaviour changes in the students that interacted with *WorkshopAR*. The tool provided a different channel of communication in an activity that the students were struggling to implement and offered learning tools to improve the collaborative skills during the early stages of group consolidation. The tool was also consuming too much time in configurations and that was affecting negatively the time management process of the group.

Overall, it was shown that the unique characteristics of AR can be used to implement an effective collaborative learning approach that promotes interesting forms of communication and learning, but also poses substantial challenges based on the hardware used to deploy the solution and how much the technology has to integrate with the academical work of the students. Both positive and negative results are valuable lessons that can further the research in education or to be a starting point to explore other forms of implementation of this technology.

7.2 Guidelines and Recommendations

Although the implementation of *WorkshopAR* is strongly tailored to the case study of the Industry Project course, it is possible to extract some learned lessons derived from the implementation process, the hurdles identified and the feedback gathered from students and test users. Hopefully, these ideas can be extrapolated or at least offer guidance in other types of scenarios, either helping in the design and implementation of AR technologies or by considering a similar approach to learning activities, either using AR, CL or a combination of these elements.

WorkshopAR was build with the idea in mind of *augmenting communication*, and this idea was born from the goal of capitalising on the main advantages that AR offers: strong visuals, awareness of the context and high mobility. When working on designing a tool based on AR, the stronger results come when properly identifying what is being augmented, not only what is being shown in the screen. This augmentation often uses visuals elements, but interactions, movements, animations and the overall user experience build are also an essential part of emphasising that augmentation.

In matters more technical, the technology is evolving, specially in the front of development tools. The needed infrastructure to support a multiuser experience was entirely provided by the *Lightship* framework, which facilitated the focus on the experience design rather than in networking issues. It is a major advantage that enables experimentation and innovation. And yet, the implementation process still requires highly customized code and technical solutions, which are simply not feasible for someone without a technical background. If it is the objective of any project to implement AR as a solution, a couple of considerations derived from the experience in the creation of *WorkshopAR* can be of use:

- Unless the technical challenges of a project are the focus of development, there is no need to reinvent the wheel in matters of augmentation, visualisation and deployment techniques. Frameworks like Niantic and Vuforia, hardware-focused toolkits like the Meta environment or AR Toolkit, and development engines focused on graphics and interactivity like Unity and Unreal offer the needed development backbone to facil-

itate and quicken development in a way that the focus can be given to design and customisation.

- No form of tracking technique is completely stable. It is important to accept and work around a fair bit of jankiness in the presentation of visuals. It is also important to design and provide different tools to quickly reset and recalibrate the image recognition as a needed usability requirement.

- AR toolkits are strongly dependant on available hardware. Frameworks like Unity's OpenXR facilitate multiplatform development, but specific functionalities, specially for image recognition techniques, are still strongly linked to the capabilities of the deployment hardware. Additionally, AR in general is still very resource intensive, and low-spec hardware will struggle to provide an smooth run, even if its compatible with the development.

- Interactions in AR (and XR in general) are not standarised yet. A lot of interesting techniques and approaches have been proposed, but the default implementation changes from hardware to hardware, or is non-existent. Interaction design is still a major step in the development of any AR experience and time needs to be dedicated to this issue.

From a educational perspective, the first set of guidelines can be focused on the implementation of a collaborative approach. A good portion of the analysis of the case study is dedicated to understanding how the students worked together around the challenges of the course and how they used the tools available to them to succeed. Some general applicable lessons can be extracted from that analysis:

- Any collaborative activity needs to allocate resources for support and guidance of the students. This support needs to consider the different approaches that students used for collaboration and the different levels of structure that some groups need and others don't.

- Collaboration between groups is as valuable as the teamwork present inside one group.

- Groups struggling to function properly will hardly find a solution by their own. The guidance and intervention of the lecturer is often needed, and a hands-off approach to this type of conflicts seldomly yields good results.

By specifically taking into consideration the case of an AR tool used for education, the major insight that can be given is to be creative. The possibilities around what can be used inside the classroom and what can spark the interest of the students is influenced the most by the educational design rather than by the technological implementation. For this type of tools that rely a lot on strong visuals and interactions, the most important recommendations are:

- To manage the amount of distraction and side-tracking that the experience can generate. Self-exploration approaches can minimise this inconvenient, but a clear structure and guidance from the educator is always a necessity.

- To manage the time used for setup and troubleshooting carefully. This is unavoidable and needs to be accounted for in the lesson plan, especially for new developments that students are not familiar with. Time and patience is needed.

- To consider the augmentation part of the design, as mentioned in previous points. AR as an educational tool can offer and interesting and memorable link between something physical of significant inside the classroom and a concept that is hard to visualise or interact with. The focus should not be that much in the visualisation but in the connection between the visual elements and the context in which it is happening.

7.3 Future Work

WorkshopAR was developed following an iterative process aimed at polishing features in each cycle and to explore the ideas found by gathering feedback from the users. Through this procedure, adjustments to the inconsistencies in the interaction design were identified and implemented, and the emotes feature was expanded when it became a focus of interest for the students.

Additional iterations over the development of *WorkshopAR* would continue with this process of expansion of the features that students found compelling but were not complete enough. Specifically, it could be of interest to provide the following expansions:

- Annotations using other forms of multimedia beside images and text, potentially expanding the configuration process to incorporate content that could be found on the local storage of the device or on the web.

- Reimagine the play models feature to become a tool for augmented presentations. This idea came from conversations taking place with the students when asked how to make the play models tool more relevant for their work in the course (see Sections 6.4.2 and 6.5.2). The interactions proposed included a shared presentation of three-dimensional information to explain the proposal of the group to the clients or the use of presentation slides and posters that could be projected and interacted with in the room. All these ideas hinted at a tool that supports a more structured form of communication and exposition of information.

- Incorporate the role of the teacher as initially proposed in the interaction design, offering tools to visualise and interact with the work of many groups at the same time and integrating the teacher and other similar roles into the workflow proposed by the students.

Considerations on how to propose a more sustained deployment of *WorkshopAR* were also discussed. In terms of infrastructure, the services provided by Niantic through the Lightship framework (called Niantic Spatial as of 2026) provide a robust development toolkit meant primarily for testing and prototyping, but a more robust solution would be needed for production deployment. Amazon offers a lot of services meant to help with these types of graphic-intensive technologies, and Niantic is working on offering a more robust hosting

infrastructure, but for now that is a development hurdle that has to be solved in-house by an amalgam of different technologies and frameworks.

A version of *WorkshopAR* that focuses primarily on general communication features could be offered to students as an additional tool for supporting coursework. Access to the tool could be offered through the LMS supporting the class or the software library often provided to students through institutional systems, and always as an optional tool that lecturers can suggest and students could install in their own devices if they considered it useful. It was very clear throughout the observations that *WorkshopAR* worked the best when the students themselves approached it when needed and not when forced as part of the structure of the classroom.

There is also an opportunity to offer more specialised tools for visualisation and collaborative work around the more general communication tools. Besides the 3D presentation proposals mentioned earlier there were also ideas around BIM analysis, digital annotations of blueprints or models, and augmented tours or inspections in-situ. It is also worth mentioning that *WorkshopAR* was initially conceptualised as a tool to help in a course in mechanical design. The same tools could be used there, just in a different context. This specialisation of *WorkshopAR* could be achieved through modular development and deployment, using the same core communication features as a base install and letting the users extend the functionality of the tool with modular downloads as needed.

All these proposals are natural extension to the original design of *WorkshopAR* that can be considered to create a more robust software or, following a different approach, could be individual, smaller developments that branch from *WorkshopAR*.

The idea of a collaboration laboratory using AR and other related technologies emerged from discussions with the students about how to create a setup that deemphasises the distractions created by a smartphone and that promotes a better work mentality. The use of clamp arms in the setup of *WorkshopAR* tried to create a space more suited for consistent collaboration (see Sections 5.2.4 and 6.6.2), and students expanded that idea to incorporate other forms of hardware and activities not necessarily linked with learning. This idea tackles the problem found with excessive configuration requirements, but it abandons the premise of a Bring Your Own Device (BYOD) activity and the flexibility of augmenting any space for work. It could be interesting to dig deeper into these ideas of fixed AR spaces for collaboration that were difficult to test due to the characteristics of the case study.

A second scenario for development appeared when discussing how to expand the annotation feature. The idea took form when some students compared the way the annotations behaved to other web tools like Miro, Milanote and Pinterest, and how students and professional use those tools to aid their creative process (see Section 6.4.2). This scenario would explore some of the recommendations made by students for the annotations to expand their use into scenarios like visual repositories of ideas, mental maps, mood boards and other similar activities.

These seed ideas for future projects and for possible paths forward in the evolution of *WorkshopAR* derived from conversations with the students and teaching staff, those that managed to relate the functionalities of the software with the needs of their work, showing that *WorkshopAR* was creating interest in the intended users. A progressive expansion and adjustment of the proposal can result in a tool that is useful to the students and helps to promote a valuable learning design focused on teamwork and collaboration.

7.4 Final Words

The development of *WorkshopAR* and its integration to the Industry Project course was a valuable example of a collaborative design and how this philosophy supports the creation of transversal skills and complex learning scenarios by encouraging social connections, collective intelligence and effective communication.

It can be confidently said that this research did produce observable changes in the behaviours of the students incorporating the tool to the workflow that the course was encouraging. Students demonstrated a better communication process and had the opportunities to further develop collaborative skills, and in turn they helped to evolve and grow the project itself thanks to the feedback provided and the rich experiences that were possible to observe in the classroom, opening the possibilities to keep expanding this line of research in future work thanks to the promising results obtained.

Appendix A

Pedagogical Goals for Educational Technologies using Augmented Reality - Codification Guide

A SLR was performed as part of the literature review process guiding this research project, and the results of the codification phase of the review can be found in the following repository:

https://github.com/speregil/ar-survey-annex.git

This SLR codified a total of 67 different articles related to the use of AR in educational settings. The analysis phase of the review focused on mapping what educational goals were more prevalent in the design proposed in each surveyed project. This information was codified using the BRT framework to understand the cognitive complexity of the goals identified, while the goals themselves were codified using the verb + statement approach proposed by Fuchs and Deno (1982).

The bibliographical information of all the surveyed articles was codified using the following structure shown in Table A.1.

Table A.1: Structure of the Coded Data

Field	**Description**
ID	Unique ID for the entry
Main Author	Last name of the main (first) author of the research
Year	Year of publication
Journal/Proceedings	Name of the journal or conference in which the article was published
Author's Discipline	Main subject affiliation of all the authors of the article as best as it could be extracted by the coders. The reported affiliation to universities and faculties and simple web searches were used to determine such subject affiliation

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Table A.1: Structure of the Coded Data (Continued)

Target Demographics	Intended target demography or educational level of the project or tool. Demographics were divided in primary school (6 - 12 yrs. approx.), secondary school (13 - 18 yrs. approx.), university education and vocational training
Specific Demographics	Specifics about the subjects using for the research as test or final users
Target Field	Intended field of knowledge in which the research or tool works
AR Technology	The main AR engine used to create the tool
Additional Technologies	Other notable technologies mentioned in the research
Custom Build	If the tool was built from zero, tailored for the research, or if some third-party tool was used or adapted to the needs of the research
Goal Statement	Educational goal guiding the research as stated by the article or inferred by the researchers. The goal was coded in the + format
Explicit Goal	If the goal was explicitly stated in the research or if the coders had to infer and formulate a goal based on the information provided by the research
Success	If a project could be categorized as a success or not based on the criteria stated in the systematic review, and as best judged by the coders
Comments	Notable comments of the coders about the research
Knowledge Dimension	Classification given by the coders in the knowledge dimension as stated in the systematic review
Cognitive Dimension	Classification given by the coders in the cognitive dimension as stated in the systematic review
Positive Experiences	List of all the coded positive experiences extracted from the research and using the Positive Experiences Code Book
Negative Experiences	List of all the coded negative experiences extracted from the research and using the Negative Experiences Code Book

The fields *Knowledge Dimension* and *Cognitive Dimension* use the BRT to classify the identified educational goals. Data was coded using the keys shown in Table A.2.

Finally, the *Positive* and Negative Outcomes fields codify the main themes and categories

Table A.2: Coding Keys for the *Knowledge* and emphCognitive Dimensions of the BRT

BRT Dimension	Key	Value	Description
Knowledge	A	Factual	Knowledge of simple facts without context or immediate application
	B	Conceptual	Knowledge of complex concepts, relationships between facts and the context around them
	C	Procedural	Knowledge on the components and execution of a tasks, the reasoning behind them and how they affect their context
	D	Metacognitive	Knowledge about learning, how to learn and your own learning abilities, limitations and approaches
Cognitive	1	Remember	Goals associated with correctly and consistently remembering facts and information
	2	Understand	Goals associated with recognizing concepts, relationships and compositions
	3	Apply	Goals associated with correctly using previous knowledge in a concrete context or scenario
	4	Analyse	Goals associated with inferring and extracting new knowledge from other concepts, context or the relationships between them
	5	Evaluate	Goals associated with giving a value judgement based on knowledge and analysis
	6	Create	Goals associated with creating new elements, procedures or knowledge

found on the recount of experiences extracted from the results, analysis and conclusions of the reviewed works. The categorisation process compiled and used the codebooks shown in table A.3 and table A.4.

Table A.3: Codebook for Positive Outcomes

Category	**Key**	**Value**	**Description**
Student Autonomy	1.1	Facilitates student autonomy	AR makes easy for students to work in an autonomous way.
	1.2	Offers student-controlled pace of the experience	The tool advances and can be used at different paces, controlled by the desired rhythm of the user.
	1.3	Offers a personalized experience	The tool changes content or presentation elements depending on the usage of the student
	1.4	Supports different types of learning methods	The tool presents the same content or activity in different ways to foster different types of learning, like visual, memory or other similar approaches

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Table A.3: Codebook for Positive Outcomes (Continued)

Accessibility	2.1	Easy access to the technology	Getting access to devices need to use the tool is easy
	2.2	Use of available technology	The tool uses available technology for the students, like their own smartphones or simple tech lab's devices
	2.3	Easy to learn	It is easy for the users to learn how to use the tool
	2.4	Unexpensive or easy implementation	The cost of building and deploying the tool is low or lower in comparison to other technologies
	2.5	Easy or intuitive interaction	The tool is easy and enjoyable to use

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Table A.3: Codebook for Positive Outcomes (Continued)

Performance	3.1	Improved academical performance is tested	Students gain academical performance using the tool and it was tested in the research
	3.2	Facilitates concentration/attention	Students or researchers reported improvements gain in concentration or attention
	3.3	Facilitates practice/training	The tool helped students to practice or train
	3.4	Improved long-term retention is tested	Students gain improved retention using the tool and it was tested in the research
	3.5	Boosts confidence in learning outcomes	Students report feeling more confident in what they learned and the long-term retention of it
	3.6	Faster/easier learning	Learning was achieved faster or students report doing it easier in comparison to other experiences
	3.7	Enhanced critical thinking is tested	Researchers tested gains in critical thinking
	3.8	Balanced learning outcomes for different students	Results for students at different levels were balanced or the gaps were minimized

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Table A.3: Codebook for Positive Outcomes (Continued)

Immersion and Motivation	4.1	Higher motivation for the learning subject/activity	Students report to be more motivated or invested in the learning subject
	4.2	Facilitates emotional investment in the subject/activity	Facilitates emotional investment in the subject/activity: Students report to be more invested with the activity, the tool or its content
	4.3	Content used encourages learning	Students feel motivated to engage with the content of the tool
	4.4	Fun or interesting tool	The tool or its content is reported to be fun for the students or presents an interesting approach to the learning material
Digital Literacy	5.1	Helps in digital literacy education	The tool can be used to educate in the use of digital devices
Visualization	6.1	Helps in the visualization of abstract/difficult concepts	The tool provides visual content to explain abstract or difficult subjects.

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Table A.3: Codebook for Positive Outcomes (Continued)

Tool Validation	7.1	Comparable or better than other VR/AR apps	Research shows better results in comparison to other tools or technologies
	7.2	General satisfaction of the subjects with the app	Users report high satisfaction with the tool
	7.3	Better tool to accomplish an objective in comparison to others	Better results in accomplishing a particular goal in comparison with similar tools
	7.4	Tool achieved some form of professional validation	The tool was evaluated and validated by professionals in the field
Multimedia Learning	8.1	Benefits of multimedia learning are noted	The use of multimedia content in the tool greatly contributes to its success
	8.2	Sets itself as an alternative tool for learning	Students see the tool as a good alternative to achieve their learning goals
	8.3	Is an alternative or better way to present a subject	The content used in the tool does a better job to present the learning subject
	8.4	Improvement when paired with other media or tool	The tool is better used paired with other content or tool
Cognitive Load	9.1	Reduce stress or cognitive load	Cognitive load on students was tested or reported to be reduced

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Table A.3: Codebook for Positive Outcomes (Continued)

Collaboration	10.1	Facilitates collaboration or socialization	The tool is used in collaborative scenarios

Table A.4: Codebook for Negative Outcomes

Category	**Key**	**Value**	**Description**
None reported	1.0	None reported	No negative outcome was reported

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Table A.4: Codebook for Negative Outcomes (Continued)

Technology Issues	2.1	General technology issues	Reported failures, problems or inconveniences related to technology usage or setup, mainly of the platform or the AR tool itself.
	2.2	Occlusion	The AR image recognition is occluded by other objects or the users themselves
	2.3	Illumination	Poor or excessive illumination
	2.4	Frame rate and computational power	The selected platform struggles to process or run the tool, creating frame rate issues or slowing down the experience
	2.5	Impractical markers or image recognition problems	The selected markers for image recognition are inconvenient, constants tracking lost or similar issues
	2.6	Connectivity problems	Connection was unstable, lost or the necessity for a connection was an inconvenience for the usage of the tool
	2.7	Budget/cost issues	The cost for creating or using the tool were too high or impossible to scale up
	2.8	Accuracy problems for geolocalization	AR is based on geolocalization, and it lacked precision or was to erratic

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Table A.4: Codebook for Negative Outcomes (Continued)

Pedagogical Design Issues	3.1	General pedagogical design issues	Issues related to the pedagogical design, the educational goals, the content presented or the activities around AR
	3.2	AR is not integrated well with other activities	The use of the AR is considered a distraction or harmful to the other elements of the activity
	3.3	AR is not correctly used as learning tool	The use of AR in the proposed project is minimal or is not related to learning
	3.4	Pacing and time consumption	Set up or usage of the AR tool consumes too much time and harms other activities
	3.5	Poor scalability of the activity	It is hard or nonviable to use the proposed tool with more users or in a more realistic scenario
Cognitive Issues	4.1	Easy to lose attention or AR takes attention from learning	The AR elements of the tool are distracting and take the attention from the learning core of the tool
	4.2	Increased Cognitive Load for students	Researchers reported an increase in the cognitive load of the students

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Table A.4: Codebook for Negative Outcomes (Continued)

Scope Issues	5.1	Scope of design too big for technology limitations	The technology used did not suited the pedagogical design
Isolation	6.1	AR promotes isolation	The use of AR prompts the students to isolate themselves and not pay attention to their peers or their context
Performance Issues	7.1	Lower or not significantly different academical results	Tests done by the research showed no academical performance increase or it was not statistically significant
	7.2	Results are not consistent between different types of users	Results show there is a significant difference in results between different types of users
Motivation Issues	8.1	No interest or motivation in the tool	Users reported or observed to have no interest in using the tool
	8.2	Novelty of the tool ended quickly	Initial interest in the tool lost quickly, before the activity ended or in a subsequent session
	8.3	Other tools are more reliable/interesting	Users found other tools more interesting or useful than the proposed tool

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Table A.4: Codebook for Negative Outcomes (Continued)

Harmful Effects	9.1	The tool harmed the development of other skills	The use of the tool had an undesired negative effect in the development or acquisition of other skills
Content Issues	10.1	Insufficient or lacklustre content	Content created for the tool was reported as low quality by students or they would wish for more or different content
	10.2	Hard to create content for the tool	Difficulties in budget, time or resources to create or procure suitable content
Usability Issues	11.1	Hard to use or requires too much training	Hard to learn and/or use, or using the tool requires too much preparation and proper training
	11.2	Physical exhaustion	Using the tool is exhausting
	11.3	Limited access to technology	The platform chosen for deploying the AR tool is hard or expensive to come by
	11.4	Difficulties with multiple users or different types of users	The tool was not well suited or received by a percentage of the user population

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Table A.4: Codebook for Negative Outcomes (Continued)

Research Design Issues	12.1	Research design has problems	Some elements of the research designs are weird or harm the overall exposition of the tool in some way
	12.2	The AR tool used is not clear	The AR technology used is not clear
	12.3	Data presented by the study weas difficult to interpret	The research presented data in a format hard to interpret or that obscured aspects of the research
	12.4	Data presented contradicts results or presents some kind of problem	The data presented contradicts statements given in the discussions or conclusions sections
	12.5	Specific goals of the research were not met	The main hypothesis of the research was proven false or the educational goals stated for the tool were not met

Appendix B

Gesture Interaction Video Library

This is a collection of 39 videos depicting the final selection of gestures derived from the research study: Interaction Gestures in Augmented Reality Collaboration. Each video shows a single gesture performed to accomplish a specific task in an augmented reality software, assuming a multi-user, collaborative setting. The gestures were identified using a user-driven design approach among 24 different participants. The final selection represents the most common proposals for each task.

Video Library: https://github.com/speregil/CollabARGestures

The gestures identified represent the proposals made by users when asked to perform gestures that could accomplish the tasks described in B.1. All the videoclips represent a gesture proposed by one or more interviewed participants. Each video is coded as TXGY where X represents the ID of the task and Y the ID of the gesture represented. Al clips are a reinterpretation of the gestures observed as proposed by the researcher.

Table B.1: List of Tasks for the Gesture Video Library

ID	Name	Description
Task 1	Pointing at an object	Point to your teammates a digital object in the shared space
Task 2	Pointing at a place	Point to your teammates a physical object or place in the shared space
Task 3	Pointing at a person	Point to your teammates another person or member of the group
Task 4	Hold an object	Hold an object present in the shared space
Task 5	Share an object	Share a held object with a teammate
Task 6	Put an object in a private space	Put a digital object from the shared space into a private one
Task 7	Undo a task	Revert any previous action
Task 8	Put an object out of a private space	Put a digital object from a private space into a shared one
Task 9	Vote for an option in a menu	Vote or select an option from a menu-like user interface
Task 10	Vote for an option in a collection of objects	Vote or select an option from a collection of objects present in the shared space
Task 11	Ask for the attention of one teammate	Ask for one or more of your teammates to pay attention to you
Task 12	Pause participation	Pause your current participation in the group's activities
Task 13	Give someone else the turn to speak	Give a teammate the turn to speak when asking for it
Task 14	Ask for everyone's attention	Ask for all the participants of an activity to pay attention to you

Appendix C

Unstructured Interviews

As part of the research methodology, two unstructured interviews were used to triangulated the data generated during the observations period of the case study with the Industry Project course.

C.1 Questionnaire for the Interviews with Students

The first interview focused on the reported experiences of the students about the work done with their groups, how did they experience the development of the collaborative work needed for the course and the mechanisms they perceived were used for team management and the execution of the project. The following was the questionnaire used for these interviews.

Question 1. When working with your current team, either in the classroom or online, where there any *rules* that the group had to follow for any aspect of the work done? Can you describe them?

Question 2. Can you describe how or when did these rules appear? Had you any influence in the implementation of these rules?

Question 3. Beside your professional role in the course itself (Quantity Surveyor, Construction Manager, Construction Engineer, Architectural Engineer), had you any other role in your group, related either to the tasks needed for each assignment or for the meetings with your group? Did anyone else in the group had such a role?

Question 4. Please, describe an example of something that went well with the group, something that was helpful in planning or completing a task or assignment.

Question 5. Please, describe an example of something that didn't work with your group, any incident or situation that hindered your group or the expected performance.

Question 6. Did your group manage to solve or circumvent that problem? How?

Question 7. Would you have preferred to complete this project individually? Or did you gain some form of value by working in a team?

This questionnaire was adapted to fit the needs of the project from the original work found in:

> Ann Noble in 2000, provided as a supplementary document to The University of Adelaide (2000). Leap into...Collaborative Learning. Centre for Learning

and Professional Development. Available from http://www.adelaide.edu.au/clpd/resources/leap/.

C.2 Questionnaire for the Interviews with the Teaching Staff

The second interview focused on the views of the teaching staff about how to best promoted good collaborative practices among the students and how this type of collaborative design affects positively and negatively the execution of the course. The following was the questionnaire used for these interviews.

Question 1. How would you describe a group using good teamwork in the course?

- What actions are they taking?
- How does it reflect in their work?

Question 2. How would you describe a group not succeeding in their teamwork?

- Any common bad habits or pitfalls?
- How does it reflect in their work?

Question 3. Can you identify any mayor difficulties of "pushing" students into proper teamwork?

Question 4. Has collaborative learning help in the overall goals of the ENBU 79X/89X?

- Any reasons for the first assignment to be individual?
- Good reasons for all assignments to be individual?
- Anything you would like to do different in the future?

Question 5. How do you deal with students that are reluctant or adverse to group work?

- Has the case of Brandon made you change something in the future?
- Any other fringe cases you ae aware of? How you delt with it?

Question 6. Does the focus on collaborative work eases any aspects of your work as a lecturer?

Question 7. Does the focus on collaborative work makes any aspects of your work as a lecturer harder?

This interview was adapted from questions and methodologies used by Chiriac and Granström (2012) and Gillies and Boyle (2010).

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