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 we need to manage our participation in a team, the overall success of our collaboration and the learning objectives that need to be fulfilled. 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 differences in approaches and methodologies between traditional and collaborative learning, the benefits of adapting one approach over the other 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 have become such important skills to develop, why is a fundamental skill to demonstrate as a professional and why is there a general feeling that educative institutions are failing in teaching those skills.

I will approach the field of CL using the lens of Technology Enhanced Learning (TEL): the use of technologies to support processes or management of teaching and learning (Passey, 2019). Understandably, this is still too wide of a subject, so, a particular 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.

My proposal is that 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, 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 educative goals are better suited for the technology and what challenges in design and development can be expected.

This chapter explores these questions and themes across three sections. The first one tackles the issue 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 shows 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 collaborative learning 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 & 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 & 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 & 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 in the worst-case scenario, 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 and in different contexts. For instance, collaboration can be viewed as a skill to be developed within the context of professional development and employability.

First, some definitions that help in building a clear view of the scenario. Fugate et al., 2004 define employability as a shared set of dimensions used to evaluate a candidate for a job. This ideal of an employee goes in two ways: the image an employer has of the professional they are looking for and the value a candidate considers is worth showing in their profile. Of the different dimension that can be used to evaluate the employability of a person, I want to highlight three: career identity, personal adaptability and social capital.

As stated by Crant, 2000, the modern workspace seeks 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. For employees, it means that they must build that career identity: the right set of skills, experience and personal traits that show value beyond 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, 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 identify some ideas from diverse sources in the literature, a 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 (Smaldone et al., 2022, Ng et al., 2021, Nadarajah, 2021, Boahin & Hofman, 2013, Llorens et al., 2017, Huynh et al., 2024, Zhang et al., 2024, Garst et al., 2019, Abir 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, are independent of the region or field. Figure 1 shows a visual distribution of the most common transversal skills sough after in potential candidates, extracted from the studies mentioned above.

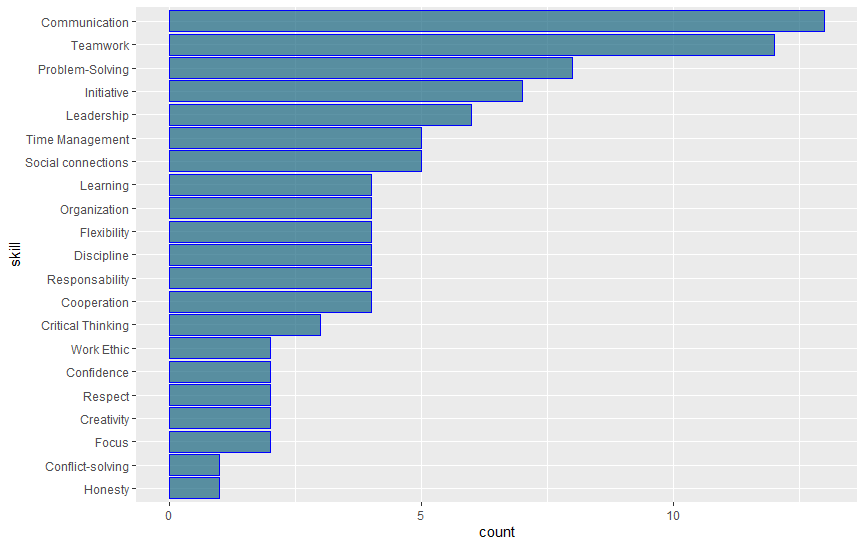


Figure 1 Most common soft skills identified

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 education institutes and those sought after by companies and employees, as identified so far in this section (Ng et al., 2021, Damoah et al., 2021).

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.

Similarly, “good old-fashioned” teamwork is an issue for young people who have a different set of values in comparison to the 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 stablished 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 curriculums 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 in the ability of a curriculum to provide such learning pathways. Most common problems are related to how little are educators 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.

To continue building the theoretical framework around collaborative learning, I will sidestep into the definition of a second concept, that of Communities of Practice, with the intention of later linking this idea with the general definition of collaboration built so far and the approach proposed by this project to use it as an educational tool.

## 2.1.2 Communities of Practice

A term proposed by Lave & 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 communities of practices 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). CoPs 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 stablished practice, as described in Figure 2.

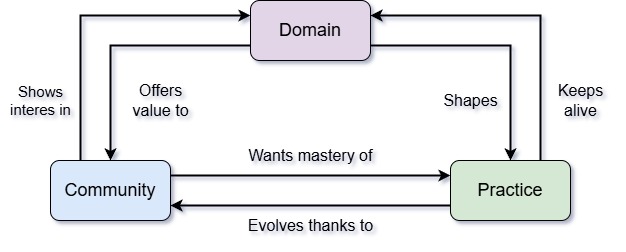


Figure 2 Elements of a Community of Practice

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 CoPs 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.

CoPs have shown to be the cornerstones in the development of informal and social learning, leadership development and organizational change (Anderson and 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, 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 and Kimble, 2004).

A particular emphasis in 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 & Duguid, 1991 have analysed the lifecycles of successful and failed CoPs 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 Community of Practice as a natural-occurring social structure formed around the need of preserving, communicating and nourishing knowledge within a well stablished 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. I will analyse these issues 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 Community of Practice.

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, we need to add more elements to the analysis. In that way, the natural structures that we expect to find 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 consider 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. We could 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 helps us visualize 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 & Valkenburg, 2008 analyse the formation of CoPs 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. Giving continuation to the initial example, a study group work the best when the students themselves want to be part of it, and it is because they recognize that they need the help of their peers or because the collaborative activity is beneficial, not necessarily because it is part of a lesson proposed by the teacher, or even worse, because is a mandatory part of an assessment.

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 CoPs. Klein & Connell, 2008 propose a series of principles used to nourish CoPs 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 & Valkenburg, 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 stablish 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 et al. 2014 echoes this idea by arguing that the significance of a CoP lays 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.

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 resources have been used in trying to understand how individuals come together as a group to achieve a goal, and to identify all the factors (internal, external, personal, emotional or circumstantial) that contribute to the success and failure of a group. The Tavistock approach, for example, offers a systematic view of the psychological dynamics present in the conformation and life cycle of a group (Bion, 2003). The analysis identifies important structures that appear inside a group like authority figures, responsibilities, boundaries (both internal and external), crisis responses and organizational structures. Participants form an 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 though, Knowles & Knowles (1972) identify 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 (Wagner et al., 2010; Dawson, 2017). When identified, these factors can be replicated and taught in controlled and varied scenarios so that students become aware of their value, build they own experiences of success and failure in a safe space and gain proficiency in identifying and replicating those same elements by themselves.

Hibbert & 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). Krug, 2001 notices that the ingrain 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).

Krug also remarks that when a person is not motivated to collaborated is because no value is perceived in the effort needed to maintain the collaboration. This perception can be explained by finding individual actions more efficient in comparison to the energy cost of managing relationships, group dynamics and power imbalance issues within the group.

One of the first steps in identifying a framework for learning how to collaborate is to identify these barriers 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 stablishes that before any form of valuable collaboration can be generate, 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 & 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 itis 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 stablishing 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, like shown previously with the main indicators of dialogue, to key aspects like:

* Ask and give support
* Analyse and challenge other’s contributions
* Analys 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 & 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 & Ulseth, 2013 and Asrori & 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 1 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 in the future as an initial standpoint for all the educational and technological developments of this research project that have collaboration as the main learning goal.

|  |  |  |
| --- | --- | --- |
| **Criteria** | **Evidence** | **Examples in Literature** |
| **A shared common goal** | Work Design | Fisher, 2014; Kernaghan & Cooke, 1990 |
| Goal and task ownership | Kropp & Dodd, 2024; Sohmen, 2015 |
| Co-creation and acquisition of knowledge | Salmons, 2019; Drejer & Jørgensen, 2005 |
| **Willingness to collaborate** | Inclusion of all members | Keay, 2006; Zubiri-Esnaola et al., 2020 |
| Affirmation of all ideas | Marasi, 2019 |
| Group bonding and empathy | Blanco et al., 2017; Widayati et al., 2022 |
| Share knowledge and resources | Nissen et al., 2014 |
| **Evaluation and self-reflection** | Quality assurance | Vaughan et al., 2019 |
| Personal and group accountability | Paris S. Strom, Robert D. Strom, 1999; Stein et al., 2016 |
| Incorporate feedback | Tausczik & Pennebaker, 2013; Díaz-Vicario et al., 2024 |
| Error and crisis responses | Furniss et al., 2011; Hayes James & Perry Wooten, 2009 |
| **Proper communication** | Decision making | Bales, 1970; Cooley, 1994 |
| Ask and give support | Drach-Zahavy, 2004; Scarnati, 2001 |
| Management of emotional interactions | Luca & Tarricone, 2001; Lee et al., 2018 |
| **Proper management** | Task allocation | Hirshfield & Chachra, 2015; |
| Self-Organization of the group | Keay, 2006 |
| Communication patterns | Jahng et al., 2010; Amponsah, 2003 |
| Flexible structure | Gross, 1997; Jacobs, 2015 |

Table 1 Evidence Factors and Assessment of Collaborative Work

## 2.1.5 Conclusion: Approach to Collaborative Learning

At this point I have explored the tools needed to properly characterize the benefits and challenges around collaborative learning. From the definition built in section 2.1.1, collaboration is a skill developed by students to achieve a common goal through a shared set of values, views and efforts. The common goal here is learning.

Section 2.1.2 introduces the concept of a community of practice and all the positive implications of using such framework in terms of understanding the motivations that drive the people partaking in collaborative work. In a CoP there is a feedback loop between participants gaining value from their participation in the community and the field of work in which they are immersed constantly evolving through the relationship between domain and practice. A proper and healthy CoP has an antagonistic view of the type of work normally found in a classroom, with little agency from the students in their participation with the domain and their practice limited in time and scope to the fulfilment of a task.

Nonetheless, exposing students to the general dynamics of a CoP has value, especially considering both the ubiquity and the transparency of such dynamics in the workspace. It is also valuable to refocus the approached used for a CoP in the classroom not as a fancy synonymous to teamwork or classroom group work, but as a tool to analyse how students in general approach their learning tasks. This can be achieved by identifying a whole classroom (or cohort, or course, or department, etc.) as the community. The practice is not a task or a project, but the process of learning in the specific domain. In the proper environment students develop tools to manage their learning and the relationships developed with peers and teachers.

Finally, in section 2.1.4 I used the information found on current literature to establish a set of criteria and evidence-base assessments that can guide a pedagogical design that wants to use collaboration as a learning tool or that focuses on collaboration as the learning goal.

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 have to 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).

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). The process of “rubbing ideas together” offer extra value to the generation of knowledge by also providing the circumstances to make connections around that knowledge (Brunei, 1997) and challenging preconceptions or stereotypes (Chima Abimbola Eden et al., 2024; César & Santos, 2006).

Collaboration is also central in the processes of knowledge preservation. Previously, I explored the role of a community of practice in safeguarding and transmitting knowledge, but this can also be seen in terms of linking individual efforts and experiences to create a bigger body of resources, to build complex insights or push forward the understanding of something (Hmelo-Silver & Barrows, 2008; Kosonen et al., 2012).

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 in search of solutions for this situation is related to academic imbalance, especially when it affects the educator and different expectations in terms of performance and achievements formed for each group member. 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; Wang, 2009). The important note is to be aware that issues with academic imbalance are common, and that there are several tools to manage them and even take advantage of them.

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 & 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.

The myriads of advantages present in building a learning experience around collaboration can be attained when the proper tools and the proper environment is provided to the students. It is also 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 in itself 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 community of practice 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 are meant to inform the design and development of learning objects, tools or experiences. Therefore, it is now necessary to analyse all the ideas so far exposed about collaborative learning in the context of technology enhanced learning, and particularly around augmented reality as a tool for education. With this approach we will have all the theoretical foundations that inform this thesis, and this is the objective of the next section.

# 2.2 Augmented Reality in Technology Enhanced Learning

Throughout Section 1 it was briefly explained how the interest in using augmented reality as a tool for education is born from an inherent interest in the technology and a perceived value that the characteristics of AR could offer unique solutions to educational problems related to motivation, engagement and communication. It is now necessary to explore the current use of the technology 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 previous sections. 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 & Fischer, 2007 propose some recommendations to incentivize effective collaboration in students, like physical spaces that facilitate interaction instead of individualization, 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 & Price, 2014 offer a systematic review which aim is understanding what is being enhanced when talking about Technology *enhanced* Learning. When categorizing 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 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 stablish more precise use of the term VLE, we can use the characteristics given by Warburton, 2009 like immersion, a sense of presence, visualization, contextualization of content and simulation of impossible or dangerous experiences. It is interesting that the author also emphasizes 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: Visualization of content, sense of presence and immersion, and a sense of collaboration or participation with other people.

Now we have a more precise definition of a VLE at hand and a set of tools to draw comparisons between technologies, in terms of visualization, 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, 2018) due to many factors, of which is possible to highlight a wider adoption of suitable technologies for deployment, like AR-capable devices and phones. 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 Virtual Reality some years prior, successful applications and explorative research was boosted thanks to new toolkits and able technologies that facilitated learning and development.

In contrast to VR, the resources needed to develop and deploy an AR solution are in comparison 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, Liu, Cheng, & Huang, 2017; Saidin, Abd Halim, & Yahaya, 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, Englehart, Furst, W.H., & Krathwohl, 1956). 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 (Anderson & Krathwohl, 2001). It can be seen as the initial blueprint for the design process of any educational material (Healy, Taran, & Betts, 2011) and it has also been used as the basis for stablishing 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 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 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 example of action verbs that can be used to describe each intersection. These examples were constructed using as reference the works of Stanny, 2016, Newton et al., 2020 and Radmehr & Drake, 2017, which perform an amazing job at compiling, synthetizing and organizing reported lists in the literature of common action verbs used at each level.

Tabla

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Figure 3 Bloom's Revised Taxonomy with Example Verbs

This visualization 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 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.

A systematic literature review (SLR) methodology is used due to its main premise of being replicable (Siddaway, Wood, & Hedges, 2019), to serve as a tool to encourage discussion around the type, quality and quantity of the sources used for the review, and to enable the comparison of results given different search, filtering, or codification parameters. This SLR process consisted of four distinct phases: selection, filtering, codification, and a final analysis.

### 2.2.2.1 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 – 2016 period (Altinpulluk (2019); Arifin, Sastria, and Barlian (2018); Chen et al. (2017)*,* among others*)*. It was better to focus 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 augmented reality in the title, abstract or key words list. The term had not to be exclusive or opposed to virtual or mixed reality, 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, XR and MR interchangeably. Specially the terms Mixed Realities and XR are common umbrellas for more specific technologies and 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) AND (Project OR Case Study)
* (augmented reality OR mixed reality) AND (education OR training OR application) AND (review OR systematic review)
* (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. I only explore the first 10 pages of indexation 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 technical approach to mixed reality 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.

### 2.2.2.2 Filtering Phase

In this phase I reduced the amount of literature to be reviewed to truly relevant material with enough reported information for any analysis to be possible. A first set of criteria were used to exclude projects:

* Use of VR rather than AR or a form of mixed reality that did not fit well into the augmented reality 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.
* 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.

### 2.2.2.3 Codification phase

In this phase, a research team extracted the relevant information from the selected literature; it was done by two different researchers and finalised through consensus. The two researchers classified the information 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 where 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 clear that publishing a report of an unsuccessful project is not a common practice either. 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.

The last stage of codification consisted in positioning each pedagogical goal into the BRT given its perceived cognitive and knowledge complexity. In all stages of the pedagogical codification, each researcher gave its own analysis and classification for every text individually, then reached the final codification by consensus. The final codification for every text surveyed can be consulted in annex 1.

Figure 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).

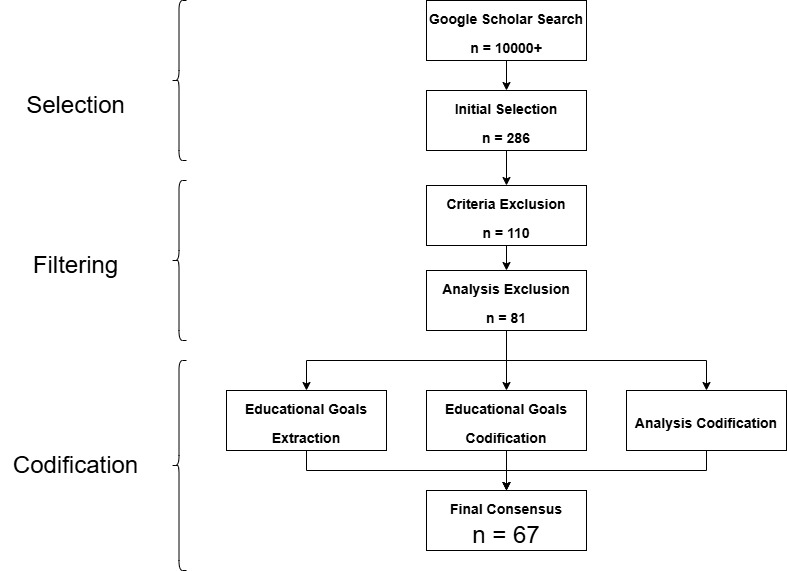


Figure 4 SLR Process

## 2.2.3 Analysis Phase

In the final analysis I used several statistical tools to extract useful insights of the behaviour and tendencies of the surveyed data. To answer the questions proposed in previous sections of this chapter, I focused on information related to the general distribution of the surveyed projects among different demographics, different educational levels and educational fields, the experiences reported by the researchers and the users, common trends and positive and negative outcomes. Finally, an effort was done to identify the pedagogical goals targeted by each project, their distribution and significant trends.

### 2.2.3.1 Demographics, educational levels and target fields

Figure 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.

Escala de tiempo

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Figure 5 Target Demographics vs Target Field

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 specializations (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 technologies.

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, Beyers, & O’Brien, 2016). 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 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.

Gráfico, Gráfico de barras

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Figure 6 STEM vs non-STEM fields distribution

### 2.2.3.2 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. Positive outcomes were defined as results or findings aligned with the goals of the research, positive observations about the tool, the participants’ behaviours, attitudes, and feedback. Negative outcomes were associated to poor results compared to control groups, reported problems with the technology, negative feedback, or unwanted behaviours of the participants.

Figure 7 shows the recurrences of all the coded themes for positive outcomes. Figure 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 annex 1.

Gráfico, Gráfico de barras

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Figure 7 Categorization of Positive Outcomes

Gráfico, Gráfico de barras

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Figure 8 Categorization of Negative Outcomes

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 feedbacks. In contrast, positive results associated with socialization 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. The result is that an important percentage of the surveyed works do not mention problems or shortcomings at all. Is more common for projects derived from engineering or computer science to 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 more 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 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 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 9 shows this cross-reference for projects coded as successful, while Figure 10 does the same for projects that were not coded as such.

Gráfico, Gráfico de barras

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Figure 9 Negative Outcomes of successful projects

Gráfico, Gráfico de barras

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Figure 10 Negative Outcomes of unsuccessful projects

It can be noted that the density of negatives experiences reported by projects categorized as successful is lower than for projects that were not classified as such. Also, projects categorized 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.

### 2.2.3.3 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 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.

Gráfico, Gráfico de dispersión

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Figure 11 Distribution of Educative Goals per Target Demographics

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 visualize 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 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 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.

Gráfico, Gráfico de dispersión

Descripción generada automáticamente

Figure 12 Distribution of Educative Goals per Target Subject

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.

## 2.2.4 Discussion

We found 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 general public and with a more product-focus in mind is also noted in a couple of fields.

The visualization 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. Geolocalization-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 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 visualization, 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 create 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, Billinghurst, Lindeman, and Swan (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 visualization or a real-time display of information. Gamification designs that require quick access to information, movement or the visualization 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 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 Lee (2021) and Hsu, Wenting, and Hughes (2019) 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 visualization 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 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 visualization. Some very interesting results can be achieved when augmentation is the focus of the experience, like in Lim and Lim (2020) or Schaper, Santos, Malinverni, Zerbini Berro, and Pares (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, Wang, Cheng, and Chen (2019) and Kim, Matuszka, Kim, Kim, and Woo (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 in 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 considered how AR is being used as an aide in different tasks, we can find multiple 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 categorizing and describing any project that could fit in this field.

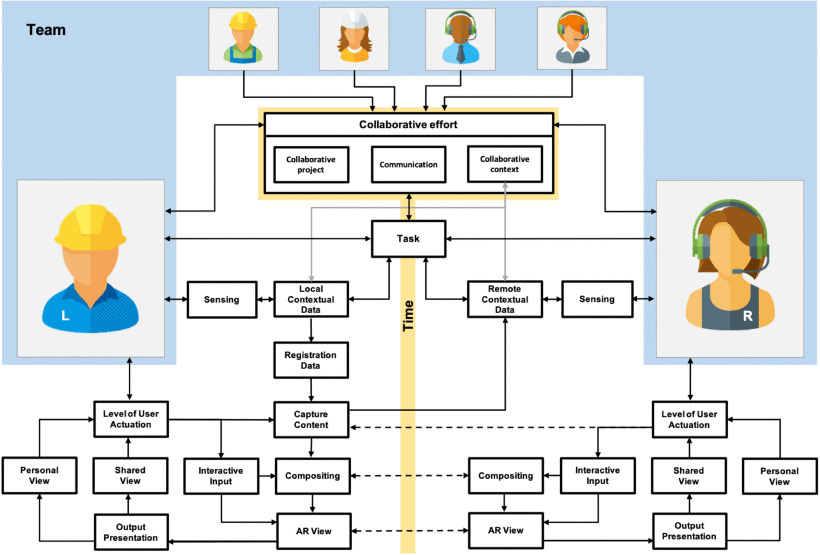


Figure 13 Conceptual Model for Collaborative AR as proposed by Marques et al., 2022, p. 6

Figure 13 shows the most important components in a collaborative AR tool that interact 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 lays 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 which have experimented a lot with the integration of AR into their work processes. Different projects experiment with tasks requiring communication of ideas, co-creation of products and balancing the workload of the team members. Wang & Dunston, 2011, for example, proposed a comparative study that showed performance improvements when using the design pipeline propose by their MR development. They focused in 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 lays 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 in 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 in the use of AR is medicine. The technology has been tested several times in diverse areas like procedure aide, data visualization 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 example shown in Friedl-Knirsch et al., 2024 or 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 have 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. They 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 visualize and guide complex procedures and research goals are relate more to feasibility and safety (Alismail et al., 2019, Jun et al., 2023 i.e.). Other common examples, like Yu et al., 2023, Augello et al., 2023 and Pooryousef et al., 2024 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: Schott et al., 2024, Gasques et al., 2021, Moro et al., 2021 and Huang et al., 2018 all show interest in providing students with tools to understand and practice learning material through visualization 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 visualization 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 & 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 prioritize 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. Their work 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 that provides early insights is The Studierstube (Schmalstieg et al., 2002), which, among several other important ideas, showed the necessity to properly think in the interaction design process of tools like this, that operate in a 3D space shared with other people, a scenario that is too distant to the common interaction and UI techniques present in desktop or even mobile environments.

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 stablished 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 capitalize on the ability of the users to be close together, but solutions must though to 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 on focus and priorities, stablishing communications, among others issues. Good examples of projects dealing with these types of issues can be found in Tang et al., 2003 and Huang et al., 2013.

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 situated collaborative AR in the field of education. My own previous SLR on the subject 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 is the educational approach used by several of the reports reviewed. Projects like Schiffeler et al., 2019, Radu & Schneider, 2023, 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 my position to focus on visualization, interactivity and mobile communications. When analysing challenges identified in the reviewed material, different authors highlight a couple of interesting ideas. In first instance, 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. Previously, it was 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 to the “noise” in the students’ performance create 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 Upadhyay et al., 2024 review and in mine in relation to what works and what not.

# 2.4 Final discussion

Through this chapter we 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, technology enhanced learning and augmented reality.

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 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. We are especially interested in exploring ideas 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 and mitigate the problems.

In the next chapter the objective will be to use the information gathered 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, I can now propose a 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.