Collaborative Educational Environments Incorporating Mixed Reality Technologies: A Systematic Mapping Study

Almaas A. Ali, Georgios A. Dafoulas, and Juan Carlos Augusto

Abstract—**In this paper, we report findings from a systematic mapping study, conducted to review the existing literature on collaborative educational environments incorporating mixed reality technologies. There is increasing interest in mixed reality technologies in education, especially with the introduction of new Over Head Mounted Displays (OHMDs), such as HoloLens, Oculus Rift and HTC Vive. with the consideration of areas such as education, dynamic technology and complex environments, a research area is identified. We carried out an extensive review of the literature from 2007 to 2017 and conducted an analysis of the works on mixed reality technologies and its subcategories applied to collaborative education environments. Results highlighted the lack of research across the mixed reality spectrum, especially in the augmented virtuality subcategory, as well as technical limitations such as response time in the development of mixed reality technologies for collaborative environments. Furthermore, the difficulty of teaching professionals to replicate mixed reality experiments in real environments, due to the technical skills required, was identified. The main contribution of this article is the discussion of the current works with visualization of the present state of the area, which is aimed to encourage educators to develop mixed reality artefacts and conduct further research to support collaborative educational environments.**

Index Terms—**Computer Supported Collaborative Learning, Collaborative Environments, Mixed Reality, Virtual Reality Augmented Reality, Augmented Virtuality, Systematic Mapping.**

I. INTRODUCTION

R ECENT advances in technology have explored the creation of virtual digital worlds [11]. These technologies can be positioned anywhere in the spectrum, ranging from real environments to completely virtual worlds, including virtual reality and mixed reality. These are referred to as a "virtuality continuum," as defined in [31]. This has brought new perspectives to different parts of society [54], especially to education at different levels, such as primary school and

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university [28]. Furthermore, it has introduced innovative and new means of communication, engagement, and collaboration. This paper focuses on the existing literature in the area of mixed reality technologies and its subcategories, and how they have been used, especially in collaborative educational environments. A systematic mapping method has been adopted and results are discussed in detail. Finally, future work is considered.

Education is described by Lev Vygotsky's theory as "habitual learning, characterized as intellectual growing" [43]. John Dewey, another pioneer in educational theory, emphasizes that the process of education can be identified in both physical and intellectual growth, implying that intellectual growth does not only enable experience in another dimension and the ability to learn but supports the rehearsals of consequences and symbolic representations [43]. It is essential to stress that quite a few of Dewey's theories play a significant role in today's collaborative educational environments. For example, Dewey's "experiential learning," described as the need for learners to engage directly with the environment, should drive the use of mixed reality technologies in learning. Since knowledge comes from the impressions made by natural objects, an educational environment could benefit from the use of mixed reality technologies to provide such experiences and opportunities to interact with the environment. This is further advocated from Dewey's belief that education effectiveness is associated with the provision of learning opportunities that link present content with previous experiences and knowledge. Such associations could be provided in a learning environment integrating mixed reality. Dewey's view was that learners should take active part in the learning process rather than being passive recipients of information; therefore, mixed reality technologies may facilitate more active engagement.

Collaborative learning theory has roots in the works of Vygotsky focusing on the social interactions between learners and teachers as well as the mutual exploration of a subject. The definition of "collaborative learning" provided by Dillenbourg is "a situation in which two or more people learn or attempt to learn something together" [14]. With "learn" emphasizing the attendance or participation of a learning activity or course, and "together" identifying various types of social interactions, such as face-to-face, computer-aided or joint achievement in which two or more people engage. With

interaction being an important aspect of collaborative learning, it is important that groups work towards a common goal and interaction of group members is encouraged. This suggests that the success of one student often depends on other students [14]. Various technologies from web, mobile, and multisensorial media to intelligent and mixed reality environments have been incorporated and applied to support the interaction between the members and to enhance the process of reaching the common goal [14].

Examples of early uses of virtual environments for collaboration are in the form of Three-Dimensional Virtual Learning Environments (3-D VLE), which include a software system simulating physical movements and objects, as well as Three-Dimensional Virtual Worlds (3-D VW), a persistent virtual world, such as Second Life. This has resulted in many educational institutes establishing virtual universities and campuses [5]. The possibility of users being immersed in one of these virtual environments without the need to be physically co-located has introduced new opportunities for collaborative learning, immersion, experimentation and interaction [41], [38], [11].

Our research is focused on the support provided towards collaborative learning with mixed reality technologies. In our research, we aim to determine collaborative settings that include 1) a learning situation between peers, 2) interactions taking place between group members, 3) mechanisms that are intrinsically collaborative and 4) the effects of collaborative learning on learners, in line with Dillenbourg's views on collaborative learning situations [49]. Our view on collaborative learning is focused on how teams work together and negotiate towards constructing shared knowledge. In particular, we are in line with creating joint problem spaces, as discussed by Roschelle and Teasley [50], comprising an "emergent, socially-negotiated set of knowledge elements, such as goals, problem state descriptions and problem-solving actions."

The authors are particularly interested in Stahl's terminology for phenomena at the individual, small-group and community levels [61], [62]. The existence of three levels of description caused us to consider whether the virtuality continuum must be adapted to reflect the existence of these different levels. In particular, learning activity, communication and context of activity have been considered. This research focuses on small groups rather than individuals or larger communities. Therefore, when discussing each technology our emphasis is on the level descriptor corresponding to small groups. For example, building knowledge (in relation to learning activity), interaction (in relation to communication) and shared space (in relation to context of activity) are focused on. The authors decided not to introduce yet another set of criteria for classifying published works, as it would further fragment the samples of works considered in this paper.

We consider collaborative learning as a process that is based on a number of stages, commencing with individual knowledge and views until social knowledge building is achieved through computer-supported cooperative learning [52], [53]. Finally, our efforts to understand the domain and also the way our students engage in collaborative learning are based on scientific visualization of learning processes, similar to the collaborative visualization discussed by Roy Pea [51].

An example project where collaborative learning is successfully demonstrated in 3-D VW is Time2Play, where users create and demonstrate stories collaboratively in Second Life [38]. Advantages highlighted by the students from other educational projects implemented in 3-D VWs and 3-D VLE included the ability to engage in an experience that would otherwise be impossible in the physical world and the opportunity to experience unique classes [42]. Furthermore, it showed noticeable impact on student participation, satisfaction and achievement [24]. Despite the advantages offered, such as the possibility to monitor, store and process all interactions performed by students, some difficulties have been noted in assessing students in a standard manner. For example, in virtual reality environments users' actions can be better monitored, leading to improved feedback [35]. These previous experiences and early developments, such as Second Life, still provide lessons and guidance for future virtual environments that are successful and more sophisticated.

The aim of systematic mapping studies is to structure a research area, which in the case of this paper is the impact of mixed reality technologies on collaborative learning. The authors conducted a systematic review for gathering and synthesizing evidence of the trends and gaps in the identified research field. The majority use different variations of the systematic mapping method, approaches and guidelines [39]. In this paper, the guideline presented by Petersen *et al.* [39] is followed for the systematic mapping study and is explained in more detail in the next section.

More recently, technologies within the virtuality continuum have been incorporated into educational environments, introducing new opportunities and challenges. The future goal of our research project is to develop a collaborative mixed reality educational environment. Therefore, the investigation conducted in these early stages focuses on work where group cohesion is supported, while the actions and engagement of individual group members within groups are measured for transparent and fair assessment. The work presented in this paper provides the current state of the area, obtained through the systematic mapping study. The focus of the mapping exercise was to investigate the existing literature to see how mixed reality technologies are currently incorporated into collaborative learning, teaching and assessment activities and the supporting environments.

The structure of this paper is as follows: Firstly, in section I an introduction and brief background to the research area of this paper is presented. This is followed in section II by a discussion of the systematic mapping method adopted, with examples of how the method is applied in other areas. The findings from the study are presented and discussed, with visual graphs in section III. Further discussion is presented, where gaps identified are analyzed in section IV, and is followed by conclusions in section V.
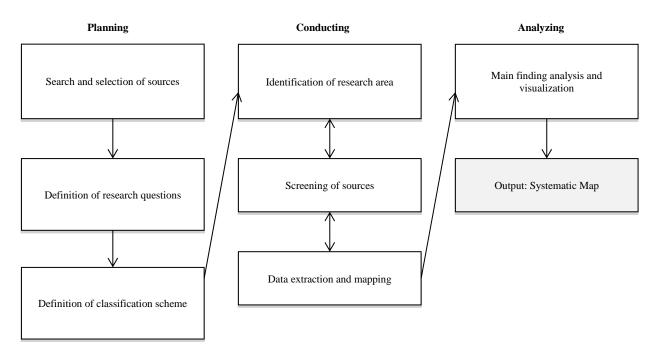
Fig.1. Systematic mapping study process implemented.

II. METHOD

The systematic mapping process followed in this study included a number of steps, as presented in Fig. 1, stemming from the definition of the research questions after finalizing the main focus of our work. The scope of the study was narrowed down to consider the incorporation of mixed reality technologies in educational environments. After carrying out the necessary searches and collecting all available papers, the next step was to proceed with a classification of papers according to their relevance and contribution to the field. The visualization of the data extraction and mapping steps is the main output of this paper.

A. Define Research Questions

A set of research questions were defined to determine the scope of study and the questions being addressed. These are listed below and in the first column in Table II.

1) Research Question 1: What is the most frequent type of research in the area of collaborative educational environments that incorporates technologies in the mixed reality spectrum?
2) Research Question 2: How have concepts of collaboration, specifically in cases of learning, reaching and assessment, been incorporated within the virtuality Continuum?
3) Research Question 3: What are the most frequent areas in the virtuality continuum (augmented reality, augmented virtuality, virtual reality, mixed reality) incorporated in education and collaborative teaching learning and assessment?
4) Research Question 4: What areas, levels and subjects in education are incorporating mixed reality technologies?

B. Define Classification Scheme

Next, a classification scheme with multiple properties for papers derived from the research questions and dimensions was noted. These classifications were aimed at enabling the collection of relevant data from the literature review and within the scope of the research. The classification of identified studies along with multiple dimensions, enabled quantifiable data to be obtained. In addition, these also created explicit inclusion and exclusion criteria for each identified study. Collaborative learning and mixed reality (and its subsections) were the main broad areas of categorization in this paper. As presented in Table II, for each of the research questions more specific dimensions and classification were defined with clear definitions. This table was used in classification of the selected papers.

C. Search Strategy and Screen Papers

An iterative search was conducted employing search terms/strings for each of the research questions as shown below.

RQ4: *("Virtual Reality" OR "Augmented Reality" OR "Augmented Virtuality" OR "Mixed Reality") AND ("Education" AND "Collaborative Learning")*

RQ4: *("Teaching" OR "Learning" OR "Assessment") AND ("Virtual Reality" OR "Augmented Reality" OR "Augmented Virtuality" OR "Mixed Reality") AND ("Collaborative Learning" OR "Group Work")*

These searches were carried out across key computer science databases, journals and conferences (Google Scholar, Middlesex University Summons, IEEE Xplore, ACM Digital

Library and Springer). The papers were selected based on the abstract and were cross-checked against the classification identified for relevance. Furthermore, a full-text reading was carried out if in doubt. The following inclusion/exclusion criteria were applied to title, abstract and conclusion as shown in Table I.

TABLE I
INCLUSION AND EXCLUSION CRITERIA

Inclusion: papers, books, technical reports presenting and describing research regarding collaborative educational environments incorporating mixed reality or any of the sub-technologies (augmented reality, augmented virtuality, virtual reality, hybrid reality).
Exclusion: *Studies not written in English and studies where full text is not accessible or only available in the form of abstracts, PowerPoint or video presentations.*

D. Data Extraction and Mapping

The data extraction and mapping process was conducted using Microsoft Excel spreadsheets, classifying and categorizing each of the papers against set dimensions (second column in Table II). A total of 148 papers were identified. Each paper included was given a unique id and papers were mapped by the co-authors, to conform with the classification as set in Table II, and internally verified.

E. Analysis

The information for all papers extracted was tabulated and visually presented with graphs (see section III). The graphs were grouped in themes influenced by the research questions. A full-text reading of the papers in the groups was carried out. Furthermore, a gap analysis was conducted in those key areas where significant gaps in the literature were identified (see section V). Further searches were carried out, to confirm gaps and aggregate evidence.

F. Application of Method

Many researchers use different variations of the systematic mapping method, approaches and guidelines [39]. Petersen *et al.* [39] reviewed the systematic mapping processes adopted in software engineering by assessing and conducting a systematic mapping study on existing systematic maps and methods.

According to Petersen *et al.* [39], the first mapping studies identified were published in 2007, with an increased interest in the software engineering community observed in 2011 and 2012. A number of reasons have been stated for this increased interest since there is a more definite distinction between systematic literature reviews and systematic mapping studies.

In systematic mapping studies the research questions are general with the aim of discovering trends and gaps in the research area. On the other hand, systematic literature reviews are more detailed studies of very specific research areas, with the aim of aggregating evidence and answering the hypothesis. This means that the process is different and more rigorous quality assessment is required for conducting a systematic literature review, involving considerably more effort and time [4], [21].

The most commonly followed and cited guideline for systematic mapping in software engineering is that provided by Petersen *et al.* [39]. However, often multiple guidelines are combined as an individual guideline, to characterize the whole mapping process [40]. The guideline presented by Petersen *et al.* is followed in this systematic mapping study.

There are numerous examples in the literature where systematic mapping has been adopted: Barn *et al.* [4] used the method of Petersen *et al.* to review and report an entire publication output of the Indian Software Engineering Conference (ISEC), visually representing the nature of Indian Software Engineering academic research between 2008 and 2012, and identifying what ideas are being studied, what the main approaches are and who is carrying out the research. Overall, the systematic mapping approach has made it possible to determine the overarching landscape of that particular area. Similarly, Dicheva *et al.* [12] carried a systematic mapping study of application of gamification to education, covering existing work including articles and conference papers published. Interestingly, it can be seen from this example how mapping studies are modified to the research aims and more topic-related facets specified as "game elements" and "education level."

III. FINDINGS

A. Research Type and Relevance

A total of 148 papers were screened and mapped as part of this systematic mapping study. Papers with more than one research type were classified according to the primary focus. As demonstrated in Fig. 2, it was found that a majority of 36% of the papers were primarily of the evaluation type (see Table II for definition). Despite the large number of papers which were of evaluation type that incorporate technologies in the virtuality continuum to educational activities, the evaluations for augmented reality, virtual reality and mixed reality systems tend to be limited in scope and rigor. The following are evaluation methods identified from literature that have been adopted for mixed reality systems: questionnaires and interviews, inspection methods and user testing, as well as user acceptance and usability [15].

One of the key findings of the literature review was that virtual reality and mixed reality research largely focus on building ad-hoc systems that are evaluated in artificial and informal settings [15].

As shown in Fig. 2, similar numbers of papers are published under the categories of proposed solutions and review of how the vision of incorporating augmented reality, mixed reality, virtual reality and augmented virtuality technologies in education is growing. This finding was also discussed in the literature review of Antonioli *et al.* [2], where the research, challenges, reactions and application of augmented reality were covered. This work highlighted possibilities for more student-centered and collaborative educational opportunities enhanced by augmented reality technologies.

There is an increasing research publication trend in the area of incorporating mixed reality technologies into education, especially collaborative educational activities. In particular, from 2011 until 2016 there is a significant increase, as shown in Fig. 3.

TABLE II
RESEARCH QUESTIONS, DIMENSIONS, CLASSIFICATION AND DEFINITIONS

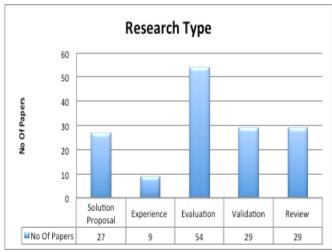| Research Question	Dimension	Classification	Definition
What is the most frequent type of research in the area?	Research Type	Solution Proposal	A solution for a problem is proposed
		Experience	Explains what and how something has been done in practice
		Opinion	Expresses the personal opinion on whether a certain something is good or bad, or how things should have been done
		Evaluation	Implemented in practice and an evaluation of the implementation is conducted
		Validation	Approach investigated is novel and has not yet been implemented in practice (e.g., lab experiment)
		Review	Review of literature and/or existing projects, models, frameworks, etc. is conducted and discussed
How have concepts of collaborative educational cases in learning, teaching and assessment been incorporated to the area of reality and education?	Collaborative education	Present	Elements of collaborative education cases are discussed/presented
		Not Present	No elements of collaborative education cases are discussed/presented
What are the most frequent areas of the Virtuality Continuum incorporated into education and collaborative teaching, learning and assessment?	Type of interaction	Virtual Reality	Computer-generated simulation of a three-dimensional image or environment that can be interacted with using software or hardware
		Augmented Reality	The integration of digital information with the user's environment in real time (e.g., overlays)
		Augmented Virtuality	The integration of real-world objects and interactions into virtual worlds (e.g., gyroscopes)
		Mixed Reality / Hybrid Reality	The merging of real and virtual worlds to produce new environments and visualizations where physical and digital objects co-exist and interact in real time
		Education-focused Application (EfA)	Work that is commonly referred to as mixed reality, or its subcategories, but does not follow definition [31]. This classification includes research that combines work from other classifications with emphasis on providing applications that address issues within the education domain.
What areas, levels and subjects in education are incorporating mixed reality technologies?	Teaching, Learning, Assessment	Teaching	To give lesson/instruction about (a particular subject) to a person or group (teacher/instructor perspective)
		Learning	The act or process of acquiring knowledge or skill (student perspective)
		Assessment	To evaluate, measure, and document the learning progress, skill and knowledge acquisition, or educational needs of students
		TLA (Teaching, Learning, Assessment)	All aspects of teaching, learning and assessment
	Level of Study		Level of education or study which research focuses on (e.g., primary school, university, further education, etc.)

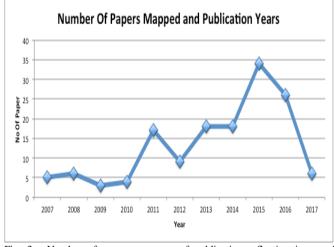Fig. 2. Graph showing the research type from the mapping.

Fig. 3.   Number of papers per year of publication reflecting increased application of mixed reality technology and research.

B.   The Reality–Virtuality Continuum

The Reality–Virtuality Continuum, shown in Fig. 4, is key in defining Mixed Reality technologies and is referenced in a large number of research papers in the area [31]. This continuum is used to classify the large scope of reality technologies and covers all possible variations, subsections and compositions of real and virtual objects and environments.
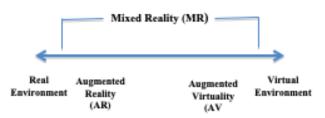

Fig. 4. Representation of a "virtuality continuum" [31].

The range spans from real environments to completely virtual environments. This includes augmented reality, which brings virtual notions to the real world and is nearer to the real environment on the spectrum of reality technologies. The majority of the research identified in the mapping study used augmented reality technologies, implemented in different ways for educational environments [1], [2]. One interesting paper discusses the use of an augmented reality interface for collaborative learning to enhance teaching. The work has been piloted at the University of Sussex and City University in the U.K. in the Informatics and Multimedia subjects [23]. This research study used Over Head Mounted Displays (OHMDs), where users were able to view and manipulate 3-D representations of computer hardware parts. It has been stated that the future of educational applications using augmented reality environment may enable student information, such as grades, needs and attendance, to be overlaid and projected in the environment [5], [55]. There is also evidence that OHMDs can be used in various ways for supporting learning activities, such as feedback provision to learners; mentor support for a range of tasks; peer observation and also evaluation of learning processes [10], [56].

Augmented virtuality is where real-world notions and objects are inserted into virtual environments, which is nearer to the virtual environment on the spectrum. As shown in Fig. 5, only one study [45] was found on this mapping with reference to this concept that discussed opportunities for mixed reality games and related scenarios for learning. This work also stated several issues and educational challenges to be addressed specifically when linking augmented reality and augmented virtuality [45], such as network connection and time required for preparing learning activities. A prototype ARLearn was developed which demonstrated in several scenarios the applicability of augmented reality and augmented virtuality in education, including collaborative activities. Activities included teaching about architecture, buildings and their history, both in the physical space using mobile devices as well as the virtual environment. The mix of the augmented reality and augmented virtuality scenarios was not explored. However, we believe there is potential in research for involving teams and groups composed of both mobile players and students, using the stationary devices in the virtual environment to create a fully mixed reality educational environment.
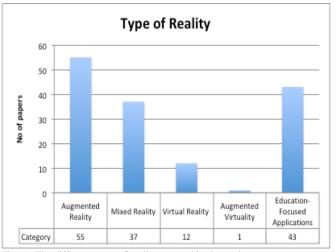

Fig. 5. The different types of reality mapped in the study.

Fig. 5 also shows that a significant portion of existing work

falls into a category that is not determined mainly from the type of "reality" but instead focuses on educational issues and the deployment of solutions from more than one classification. The sub classification of research in this area is based on the focus of the papers towards specific research problems associated with education. Although it can be argued that some of these papers would fit in a wider context of educational technology, emphasis on the work leans more towards combining different reality types to solve educational problems rather than researching the integration of reality types in education. These papers are also characterized by the tendency to combine findings from different types of reality. Furthermore, the core work presented in these papers seems to be investigating the educational context of the work and aspects of educational requirements addressed by application functionalities.

The subcategories of the "Education-focused Applications" (EfA) classification are as follows:
1) Computer Supported Cooperative Work (15 entries)
2) E-Learning (10 entries)
3) Computer-Supported Cooperative Learning (7 entries)
4) Mobile Learning (3 entries)
5) Virtual Worlds (3 entries)
6) Educational Mixed Reality (3 entries)
7) Social Learning Networks (2 entries)

C. Application of Mixed Reality to Education

As shown in Fig. 6, the majority of the research mapped was found to be focused on learning in augmented reality environments. We observed that there is no extensive research focused on applications of augmented reality, mixed reality or virtual reality technologies and environments supporting assessment activities, especially for collaborative educational activities.

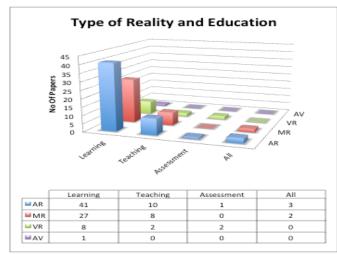|	Learning	Teaching	Assessment	All
AR	41	10	1	3
MR	27	8	0	2
VR	8	2	2	0
AV	1	0	0	0

Fig. 6. Type of reality and education.

In this paper, when we refer to teaching, we focus on teachers' perspectives in relation to the particular subject being taught. For example, one of the key publications covered in this review [34] emphasizes the importance of the virtual teacher's position, and orientation and its impact on learning efficiency in a mixed reality physical learning support system is mentioned. This was of particular interest, especially as students were required to imitate the virtual teacher in the physical environment. Software was developed and assessed for automating the virtual teacher position and angle to the best optimal position relative to the task. Findings revealed the software was effective "for motions that gradually reposition the most important moving part" [34].

Research that was of particular interest to us focused on the development of a range of augmented reality resources, drawing upon co-design research workshops with children and teachers. This line of work highlighted the impact on the students who used the prototype, including increased initiative and concentration in analyzing, sharing and discussing [8], [23].

It should be noted that teachers expressed concern that they may not be able to replicate and manage experiences themselves without the presence of the researchers [2]. Similarly, several applications and tools were demonstrated and analyzed, such as virtual worlds and tangible interfaces where users interacted with digital systems via physical objects in order to create a mixed reality system for teaching, learning and assessment activities for subjects such as language and algorithms. This also demonstrated a positive impact on learning. The tools, however, do not include authoring tools for teachers to use in developing educational activities and other concerns identified include response time, speed of network and their possible negative impact on usability [28].

Several works also focused on the students' perspective in learning and the process of acquiring knowledge or skills. An application for learning a foreign language (Spanish) in a mixed reality environment was developed, where events were carried out in the virtual world but enriched with information from the real world. This contained activities for exploration, collaboration and communication. The results showed a positive effect on students' motivation and improvements in learning [22]. During a practical exercise, students gained experience of virtual reality technologies, such as 3-D scanners, OHMDs, data gloves and 3-D Displays. All of these were aimed to advance the theoretical knowledge of virtual reality technology, as well as experience and have a better understanding of advantages and problems associated with virtual reality technologies. Feedback from the students was collected, which discovered that schools were the least likely place to experience the use of 3-D interfaces [44].

According to a review of augmented reality applications in education, there has been no long-term study focusing on providing guidelines for implementing augmented reality environments that will ensure student growth and achievement of learning goals [2]. Mixed reality visualization could be used alongside gamification to improve conceptual understanding in ICT. The use of scaffolding learning chunks, such as gamification units, can be enhanced by the use of media such as "2-D images, videos, graphics, simulations, and 3-D models applied into the design process to promote active learning in the classroom" [32].

Furthermore, according to Barsom *et al.*, there is evidence for the recent increase of augmented reality in the field of medical education. Their review of a total of 27 studies identified three categories where the technologies have applied, including "1) laparoscopic surgical training, 2) mixed reality training of neurosurgical procedures and 3) training echocardiography" [3].

Based on the majority of papers integrating technologies in the mixed reality spectrum into educational environments and activities, we observed positive impact on the student learning (see, for example [22], [25], [54], [57], [47], [60]). Although most subjects mapped were from the sciences and languages, such as physics, programming and foreign languages amongst many other subjects, a small number were from the arts and music. An interactive learning system called ChinAR, which employs augmented reality, was created with the goal of providing an easy and effective way of learning Guqin, a classic Chinese instrument. The experiments presented positive interest and impact on learning, such as improved memorization and reduced practice time to achieve learning outcomes [47].

As shown in Fig. 6, from this mapping study, assessment is identified as the least researched area, especially for collaborative educational environments. For example, there is a single framework for integrating assessment to augmented reality learning activities specifically for learning basic electronics [19]. The main advantage is that this technology enables tracking of interactive events and gives real-time feedback to both learners and instructors. This work enabled instructors to design a standardized assessment framework for AR-based learning activities; this followed a three-step assessment of presentation, response and feedback.

Experience of implementing this framework identified that further studies are required to evaluate and analyze the impact of using the developed framework on students' learning outcomes and psychological states (e.g., motivation or engagement) [19]. Large numbers of applications focused on the individual technical aspect instead of team interaction skills, as a result the use of collaborative assessment is often discarded in virtual environments. Paiva *et al.* [35] discussed the advantages of using a collaborative virtual environment for training and assessment of surgical teams, such as real-time feedback and performance report aimed for use by teaching and learning professionals [36]. Furthermore, there is a lack of well-defined metrics in assessing students in a standardized manner in collaborative virtual environments, especially in the context of users' skills assessment in health procedures [35].

It appears that the "level of study" was not clearly stated in all of the mapped papers, as the target audience was not clearly specified. Therefore, these papers were classified as Education-focused Applications (EfA) for this mapping study. The largest number is found to have been conducted for higher education environments, followed by those in secondary schools. Virtual reality technology, as can be seen in Fig. 7, is applied more for training environments such as maintenance of aircraft, information technology equipment and manufacturing products, which can be seen as useful and with

potential, due to the possibility to design learning applications with visualization to learn complex technical maintenance processes [17]. No research in Further Education (FE) was found where any of the technologies were applied. FE is a term used in the U.K. education sector to refer to "education below degree level for people above school age." It appears that there is lack of literature on the application of such technologies in FE case studies. This may be interpreted as a combination of the lack of resources and expertise in FE in conjunction with the infrastructure needed for setting up experiments and studies incorporating mixed reality in educational environments.

D. Collaborative Educational Environments

Collaboration is the action of working with someone to produce something [7]. Collaborative learning is an educational approach that involves learners working together to solve a problem or create a product, providing students with an opportunity to actively discuss and express opinions and ideas. From this literature review, we found that augmented virtuality technologies/environments have been identified as the least researched areas in relation to collaborative learning activities, whereas augmented reality technologies seem to be the most applied to collaborative learning activities. Some argue that this is because augmented reality supports the natural means of communication and interaction [58].
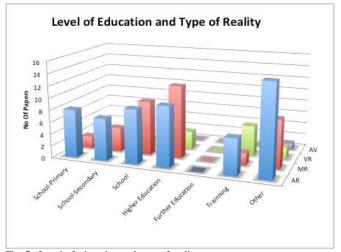

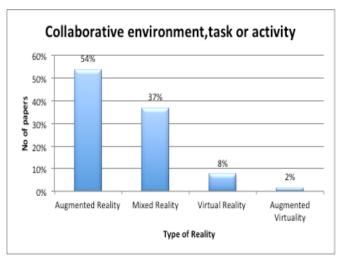Fig. 7. Level of education and type of reality.

Fig. 8. Collaborative environment tasks and activities in different types of realities.

Huang [18] presents a collaborative system that aims to teach students about human anatomy and obtain knowledge about individual organs and apparatus in 3-D space. This work highlighted five essential success components for collaborative learning environments:

1) Positive interdependence, where the individuals believe they are working as part of a group and contributing equally, with own roles and task responsibilities clearly established.

2) Promoting interaction with activities, where resources, ideas and experiences are shared. This most importantly relies on an effective communication infrastructure.

3) The individual accountability of completing the tasks assigned, as well as the group accountability of meeting the set objectives, is important, which is supported by systems monitoring progress and status of individual members and tasks.

4) Interpersonal skills are essential in managing and resolving conflicts in groups.

5) Group processes and information on how the group is functioning should be provided, where individual members receive feedback on participation and analysis of group performance.

In our research we use these success elements when designing collaborative learning activities supported by mixed reality technologies. Furthermore, the use of mixed reality simulations has been proven to enhance "enacting concepts and experiencing critical ideas" through whole-body activity. This can lead to "significant learning gains, higher levels of engagement, and more positive attitudes towards science" [25].

A coding scheme is proposed by Matcha *et al.* [27] to be used not just for performance, but for evaluating collaborative learning and measuring communication and interaction. Traditional methods for evaluation of collaborative learning environments are made through performance measures, where the amount that the students have learned is the main concern [27]. However, it is alleged that performance is not the only element that confirms the existence of collaboration between group members. As a result, Matcha *et al.* [27] propose the

additional analysis of events, such as communication and interaction.

The analysis of this process was carried out using the coding scheme proposed, where information such as the gaze of the participants was extracted from video recordings as well as annotated actions and events that occurred [27]. Results from this analysis not only showed that a number of natural interactions, including verbal and nonverbal, occurred, but also it suggested the importance of incorporating physical objects in a collaborative augmented reality system. We feel this is a very significant contribution to the field towards the enhancement of collaborative learning environments.

A review [28] conducted of existing literature in educational developments of augmented reality tools highlighted research opportunities in the facilitation of student-focused learning and enhanced collaborative learning environments. This review also identified the challenges and concerns of incorporating augmented reality technologies into collaborative learning environments prior to the stage of students having developed the collaborative problem-solving skills and behaviors necessary in a real environment. Our work reported in [59] provides an example of student-focused learning environments that help us to identify student needs in collaborative learning settings to better align the support provided by learning spaces.

Similarly, there is evidence that augmented reality technology opens up opportunities which, coupled with the right pedagogies, can significantly enhance the development of university students' laboratory skills [1]. For example, a particular study of a jigsaw method was applied in which students had independent roles that relied upon one another to complete the task. The majority of the studies suggested further analysis is required as to what types of augmented reality platforms would be the best fit for educational purposes [28].

Riot *et al.* [37] proposed a model and implementation that attempts to mix intelligent environments to distributed collaborative learning environments. They discuss the conceptual architecture underpinning this tool and illustrate its implementation using three collaborative learning scenarios. However, a number of significant barriers to advancing research were identified in the area of smart environments, most notably the lack of available environments, standards and tools, which is why simulated spaces were used instead [37]. We feel that there is a gap in this field and our research attempts are directed towards identifying how to enhance such environments for collaborative learning by introducing innovative uses of learning tools. A review of the related concepts and lessons learnt from experience, as well as the development of a prototype for a mixed reality learning space, also discussed the need for learners to be able to use multiple senses (e.g., visual, auditory, tangible, haptic and olfactory stimuli) when interacting with remote lab devices [13]. Our current work focuses on using sensors collecting data in relation to multiple senses during various learning activities, as well as using them to understand how collaborative learning may be affected by the use of smart learning environments.

Cost is still seen as a key challenge in developing such systems [18], as well as significant software and hardware improvement to enable ease of collaborative interactions [20]. Presented in this systematic mapping study are several findings discussed in more depth in the following section.

IV. FINDINGS IN THE TECHNICAL LITERATURE

A. The Use of the Term "Mixed Reality"

Firstly, it is important to highlight the use of the term "mixed reality" as it was found that some sources refer to this as an independent concept and others as a spectrum for mixed reality technologies, where its usage does not directly reflect the definition in The Reality-Virtually Continuum [31], which is key in defining mixed reality technologies.

For example, the Mixed Reality Teaching & Learning Environment (MiRTLE) [6] has the aim of developing a mixed reality meeting environment to foster a sense of community for both remote and co-located students. With remote students in the virtual environment projected into a large display in the physical classroom; the lecturer is able to interact with the avatar representation of the virtual students via audio and written communication. Furthermore, the lecturer is able to simultaneously interact with the co-located students in the classroom. This can be achieved by connecting the two worlds to create a mixed reality environment in which a live stream of video and audio of the lecture is embedded in the virtual world [6]. Whereas, Earths Shake simulated an earthquake to teach physics using a table with physical blocks which were projected using a Kinect Depth Sensing camera and vision algorithm in a virtual environment. Movements in a virtual table or physical table, which students were able to control via a mouse or physical button, were synchronized and aimed to teach physical principles of stability and balance [46].

Similarly, the Virtual Toolkit presented by Mateu *et al.* [28] aimed to enable the development of educational activities through a mixed reality environment, with the use of tangible elements to connect the physical and virtual world. One example presented with this toolkit is the Virtual Touch Book, which allows the reading of a book in the traditional way, but activities are created in the virtual world depending on the book page being read. Using Arduino technology and a light depending resistor (LDR) to detect amount of light in each page, the information is sent to the virtual world where additional materials, such as 3-D representations of the topic, are presented and can be interacted with [28].

In MiRTLE [6], the mixed reality environment was focused on merging the presence and communication of both worlds simultaneously. For the Virtual Toolkit and Earth Shake, the mixed reality environment is developed by merging tangible interfaces and virtual worlds. In their work information, actions and activities in the physical world are projected or sent to virtual worlds.

The examples presented demonstrate the various uses of the term mixed reality, where several of the aspects such as time (real time or sequential) for both interaction and communication vary. Furthermore, interaction methods vary, where tangible interfaces/objects are used as forms of communication and interaction in comparison to audio and video. It is clear from the examples discussed that the term mixed reality is used as an independent concept with a range of meanings. In reference to the Reality–Virtuality Continuum [31], the examples presented, such as augmented reality or augmented virtuality, may also be placed in the subcategories of mixed reality. For instance, Virtual Touch Book may be described as augmented virtuality, as the real-world notions are projected in the virtual world.

Due to the unclear use of the terms under mixed reality, we believe this may be one reason why augmented virtuality is not incorporated into educational environments and researched as much as other technologies on the mixed reality spectrum for collaborative educational activities.

B. Augmented Virtuality Devices and Technologies

However, technologies that incorporate augmented virtuality, where the device/program is aware of the environment, are increasingly available. The following three devices have been identified recently for development: Project Tango, Microsoft HoloLens and Meta.

Project Tango, developed by Google, is designed to develop a 3-D image of the environment using smartphones. Using motion tracking, camera, accelerometer and gyroscope, data is used to envision the environment. Combined with depth perception, it is capable of tracking distance from surfaces. Finally, it is capable of learning from past information and it uses this to enhance elements such as points of interest in a location and environment [16].

The Microsoft HoloLens is an OHMD described as mixed reality technology, which enhances the experience of interacting with projected holographs with natural interactions such as gaze, voice and gestures. Most importantly the 2-D and 3-D object may be programmed to be aware and understand the environment, such as physical space, incorporating notions of physics and real time information. Uses of collaboration have been demonstrated in both co-located and distributed environments [30]. Magic Leap has released a demo demonstrating the development concept of a mixed reality technology device. However, this is not available for development or commercial purchases [26]. Meta is another OHMD mixed reality device with 90-degree transparent view, enabling interaction with holographic objects and awareness of the environment. [29].

Zou *et al.* [48] demonstrated a platform aimed to connect various virtual labs and learning management systems with multimedia and multisensorial technologies, such as haptic, airflow and visual/audio, to further enhance the learning environment and delivery of STEM (Science, Technology, Engineering and Mathematics) subjects. This resulted in the students demonstrating enjoyment and openness to the environment. Exploring, developing or embedding such multisensorial technologies into the development of the mixed reality collaborative education environments will be considered.

Widely available technologies, such as HoloLens, show an interesting promise in the collaborative mixed reality environments. With these technologies, concepts and scenarios such as architecture that may have been limited by space are likely to be more immersive. Furthermore, interesting developments may be witnessed in distributed collaborative environments with the use of such technologies, for example when students collaborate whilst residing at different locations.

C. Assessment Activities Incorporated into Mixed Reality Environments

Next, we observed a lack of assessment activities incorporated into mixed reality environments. A number of challenges are identified in integrating technology to assessment activities despite the type of technology. We also noted that recording the users' actions whilst interacting with mixed reality technology raises privacy concerns. Furthermore, an informed consent may be required from students and parents, and how data collected is used must be communicated effectively. Collecting and extracting data from complex streams for assessment may create concerns for student privacy and viewed as more invasive. As technology-enhanced assessment may be used by students of various learning styles, different languages and learning or behavioral disabilities, concerns of equity issues have been noted, as well as pragmatic issues such as cost, practicality and utility. Concerns about integration to policy, due to the unfamiliarity of such innovations to assessment for policy makers and the integration to existing methods is expressed. Furthermore, comparing performance and learning outcome between the students in the classroom and those educated in other environments, such as those who are home schooled, highlight issues of constancy and policy because of access to the proposed assessment technologies.

D. Replicating Mixed Reality Experiments

During this mapping study we have identified several papers stating the difficulty in replicating mixed reality experiments in real environments. This was supported by the small amount of research found regarding experience type, where something that has been done in practice outside an experiment has been presented. It is important to also highlight that the majority of technologies identified in this research are at early stages of development, and thus their actual impact on learning, teaching and assessment may possibly be the reasons for the limited research in application to real environments [33].

E. Summary of Findings

In relation to the research questions stated in section II, the findings are summarized below.

RQ1: What is the most frequent type of research in the area?
1) Little research was found to have taken place in real environments and of experience types (see Fig. 2).
2) Difficulty in replicating mixed reality experiments in real educational environments and scenarios [33].

RQ2: How have concepts of collaborative education cases in learning, teaching and assessment been incorporated into the area of reality and education?
1) Collaborative concepts have been adopted in several methods from synchronous to asynchronous interactions and communications (see Fig. 6).

RQ3: What are the most frequent areas in virtuality continuum (augmented reality, augmented virtuality, virtual reality, mixed reality) incorporated in education and collaborative teaching learning and assessment?
1) Mixed reality systems/research, which implements augmented virtuality, is not incorporated and researched as much as other technologies on the mixed reality spectrum for collaborative educational activities (see Fig. 5).

RQ4: What areas, levels and subjects in education are incorporating mixed reality technologies?
1) Lack of processes for the assessment of tasks in collaborative educational environments that incorporate technologies in the virtuality continuum (see Fig. 6).
2) Small number of applications of mixed reality technologies to further education environments (see Fig. 7).

F. Future Work Plans

An initial experiment was conducted using multisensors to observe and understand elements of team member collaboration, coordination and communication in a physical space. Using multisensors and the collection of data such as emotions, participation pattern in team discussions and potential stress levels [9], enabled the identification of measurements that can be embedded in the development of mixed reality collaborative environment, especially in the assessment of individual team members.

The next step of the research involves focusing further on exploring the augmented virtuality aspect of mixed reality and embedding findings from the experiment in future pilot studies, which will be designed and run, for both distributed and co-located collaborative activities. The impact on both theoretical subjects, such as project management, and practical tasks, such as design, will be explored further.

We will explore designing further measures and data sources iteratively, considering all dimensions such as objects used, human and social aspect, as well as environment.

V. CONCLUSIONS

The findings from the studies and literature mapped in this paper are aimed to support the development of a framework for incorporating mixed reality technologies in collaborative educational environments, especially incorporating emergent technologies, in an attempt to fill the gaps revealed by using the virtuality continuum as a guide.

The difficulty of the process of this mapping study is that the search for mixed reality and its subcategories resulted in a large number of publications. However, despite the use of terms on the virtuality continuum spectrum in the title or keyword, it can be seen in the classifications that some have

been mapped as Education-focused Applications (EfA). It was after analysis that it became clear that such papers did present research under the definition. The significant volume of work that is classified according to the application of different reality types according to different educational contexts offers a possible direction for a more extensive review of the literature under the educational technology prism in the future. Furthermore, extensive searches were carried out to obtain publications where collaborative education tasks and keywords such as "team work," "group," etc., were used to ensure the research was general. Future enhancement would consider analyzing scenarios in which collaborative activities are undertaken.

Despite the limitation, this mapping study has highlighted advantages in incorporating the technologies in the mixed reality spectrum to collaborative educational activities. The recently available technologies are creating the possibility of developing truly mixed reality experiences and reducing limitations stated in literature. Furthermore, these technologies come with new forms of interaction methods, such as gesture and emotion detection, thus making it important that further research is conducted early to identify the effect of incorporating these to educational environments.

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