Immersive Virtual Reality, Augmented Reality and Mixed Reality for Self-regulated Learning: A Review

Daniela Pedrosa[1,2(✉)] and Leonel Morgado[3]

[1] Higher School of Education, Polytechnic University of Santarém, Santarém, Portugal
dpedrosa@ua.pt

[2] Department of Education and Psychology, Universidade de Aveiro & Laboratory of Didactics of Science and Technology, Research Centre on Didactics and Technology in the Education of Trainers (CIDTFF), Aveiro, Portugal

[3] Universidade Aberta & INESC TEC, Coimbra, Portugal

Abstract. Immersive technologies, such as virtual reality, augmented reality, and mixed reality have gained increasing interest and usage in the field of education. Attention is being paid to their effects on teaching and learning processes, one of which is self-regulation of learning, with an important role in supporting learning success. However, designing and creating immersive environments that support the development of SRL strategies is challenging. Employing a systematic approach, this literature review provides an overview of the uses of virtual, augmented, and mixed reality with the goal of supporting SRL. We map these to known educational uses of immersive environments, highlighting current gaps in these efforts and suggesting pathways for future studies on instructional design of the use of immersive technologies to support self-regulation of learning.

Keywords: Self-regulated Learning · Immersive Environments · Immersive Learning · Virtual Reality · Augmented Reality · Mixed Reality

1 Introduction

There is an increasing use of immersive technologies (ImT) [1–9] for education and to their effects on teaching and learning processes [10]. Common examples are X-Reality technologies: augmented reality (AR), virtual reality (VR), and mixed reality (MR), spanning the physical and the virtual, allowing users to experience immersion [2, 4].

ImT create experiences in immersive learning environments (ILE) that are influenced by several factors: interactivity, personal variables, and self-regulated learning (SRL) [6, 11]. Their adoption requires assessment along students' cognitive, affective [1, 3], metacognitive and physiological dimensions [10, 12]. Clear strategies are also needed for instructors to select and implement them effectively in learning process [10]. For example, VR can be used to support instructional design and create opportunities

D. Crawford et al. (Eds.): TIE 2023, LNICST 575, pp. 64–81, 2024.
https://doi.org/10.1007/978-3-031-59383-3_5

to teach and learn, but it's *"necessary to construct "know-how" on effective VR applications for teaching and learning"* [7]. AR may be used to facilitate the *"development of processing skills"* [13], improve learning experiences, acquire significant knowledge and for motivation [8], but presents some issues: technological, management, and cognitive [8, 9, 13], and is necessary to understand how uses of AR contribute to effective teaching [13].

VR, AR, MR can contribute to SRL [6], stimulating social presence and reflection through meaningful interactions [6, 14]. However, these environments are cognitively demanding, which affects opportunities for reflection [15] and consequently may impair SRL, since students may have difficulty monitoring activation of their motivational, cognitive and metacognitive processes [11]. So, studies on uses and integration of immersive experiences for SRL [6, 16], testing and implementing SRL scenarios [16], and instructional design suited to educational goals [17] are essential.

This literature review mapped and described the uses of VR, AR, and MR explicitly to support SRL to support instructors in applying them to their contexts and highlight current research gaps.

2 Background

2.1 Self-regulation of Learning and Immersive Learning

Self-regulated learning (SRL) is a complex process [18]: a meta-process in which students actively participate for their regulation and control of emotional, behavioural, cognitive, metacognitive, cognitive, and environmental processes [19–21]. It involves adoption of SRL strategies: self-evaluation; organizing, transforming; goal setting; planning; seeking information; keeping records; monitoring; physical and psychological environmental structuring; self-consequences; review; memorization; seeking social assistance and reviewing records [19, 21].

SRL requires skills for selection and adoption of those strategies to achieve the learning goals and development of self-awareness, self-knowledge, self-assessment, and self-efficacy [19, 20, 22]. SRL allows developing independent learners who care about what to learn and how to learn it [23], that construct their meanings, define goals and adopt strategies based on the information available in the physical and psychological environment [18].

In parallel learning environments that can leverage the phenomenon of immersion [24], a psychological deep state of mental absorption that impacts affective and cognitive processes [25–27]. The phenomenon of Immersion, arises from three conceptual dimensions [25, 27]:

1) Agency – immersion occurs when we are actively engaged in tasks that require our cognitive and physical effort (also referred to as "challenge").
2) Narrative – immersion occurs when we are focused on the story and meaning of the elements that make up the moment (characters, plot, objects, space-time contexts, sounds, images and symbols, emotional attachment, etc.).
3) System – immersion stems from the feeling of being present in an environment, be it technological, physical, social, or organizational.

These dimensions are affected by technology and other mediating elements, and experienced in immersive learning environments (ILE) where different types of immersive technology (ImT) may be employed [27].

2.2 Immersive Technologies – VR, AR and MR

To understand what we mean by ImT, we proceed by leveraging the conceptualization of the virtuality-reality continuum proposed by Milgram and Kishino [5, 28, 29], considering it as extending between the physical and virtual worlds [30]. The physical environment is positioned on the far left of the continuum and is fully realized in tangible things. The virtual environment is on the far side and is made entirely of intangible objects [5, 29]. Between these extremes, we find mixed reality (MR), considered as an umbrella term for environments that combine virtual and physical elements [29]. Among these, Augmented Reality (AR) is centrally positioned to refer to those closer to the physical world, and Augmented Virtuality (AV) to refer to those closer to a virtual environment [2, 30]. Different forms of physicality [4] and virtuality can be found along the continuum [2].

Updated versions of Milgram and Kishino's proposal have emerged since, suggesting that MR may be a very specific type of reality that lies between AR and AV [31, 32]. Skarbez et al. [33] propose that MR is an environment in which physical and virtual objects are presented together in a single perception: the user simultaneously understands the physical and virtual content in different senses. These authors agree with the original definition of AR, however, considering that external VR is also a subset of MR, since the user can perceive virtual and physical content with different types of senses (introspection). They consider that VR only occurs when all the senses - exteroceptive and interoceptive - are completely altered by virtual contents. In this sense, VR can be achieved by using computing technologies to create and simulate realistic experiences in a virtual environment [7]. It gives the user the illusion of being involved ("sense of presence") in a 360º simulated three-dimensional (3D) environment with which they can explore and interact freely and with visual objects and elements created by computer graphics [4, 7]. In VR, the user immerses totally in a virtual environment [8, 10, 12, 28, 32] "without seeing the real world" [30] and lives immersive experiences with interactions and manipulations in virtual environment [1, 4, 10].

VR includes experimental tasks through computing devices such as head-mounted displays, and natural user interfaces, like body sensors (touch, voice, gestures) [7, 12], when the "*user has a headset that generates images and sounds similar to a real or imaginary world*" [10]. It can be categorized into 4 forms of interaction: 1) Cave Automatic Virtual Environments (CAVEs) – room-sized displays involving the users; 2) Head-mounted displays (HMDs); 3) Mobile VR with portable monitors (tablets) and smartphones; and 4) wearable 360° spherical video-based VR [2, 7].

AR can be seen as a technology to create immersive hybrid learning environments that overlays virtual objects (augmented components) with physical, tangible objects, coexisting in the same space and time [1, 2, 4, 8, 9, 12, 13, 28, 30, 32]. AR is a mix between virtuality and physicality [5, 8, 28, 30], and requires triggers *"to activate a boost (a 3D material overlay)"* as *"marker-based, marker less, image-based, positional and locational AR*" [28], using the movement of a user's mobile device to display the mix environments [2, 5]. AR can be used through different technologies, such as desktop computers, HMDs, 3D glasses, tablet PCs, or popular mobile devices [9, 10]. These allow the live visualization of the physical world with integration of virtual information elements, such as sound, video, images, or GPS data [4, 10]. AR can also enhance or replace senses such as smell, touch, and audition [30], using specialized hardware, e.g.: depth sensors, eye tracking, retinal displays, and also leverage somatic human-computer interfaces: controllers, hand and finger tracking, and other interfaces such as voice commands, retinal control, or brain-computer interfaces [32].

MR, sometimes also called hybrid/extended reality, is understood as the shared interaction of experiences between the real and virtual environment [28], with physical and digital objectives coexisting mentally in real time [2, 5, 10, 12], across the entire virtual-reality continuum [28], and pursuing them with manipulation of virtual objects in the context of the physical world [4, 28, 34], in different ways [3]. The difference between MR and AR is the capacity to seamlessly interact between virtual overlays and the physical world [3, 28, 35].

3 Methodology

3.1 Planning: Purpose, Goals, and Research Question

We adopted the systematic literature review method proposed by Kitchenham and her colleagues [36]. The focus of this work was to provide an overview of uses of AR, VR, MR to support SRL.

The research question was "What is the panorama of uses of AR, VR, MR for developing SRL?" The specific goals were thus defined as:

1) Identify studies in which ImT (AR, VR, MR) are used to support SRL, in terms of a) Year of publication; b) Study field; c) Pedagogical context; d) Research Design; e) Research Sample; f) Duration of study; g) Research Instruments.
2) Identify and describe the uses of ImT to support SRL found in those studies and map them to the conceptual space of immersion.

3.2 Review Process

This review took place in October 2022, explicitly for the terms "self-regulation of learning" and "immersion". The process was organized in five phases (Fig. 1).

Phase 1 - Literature Search. Search for relevant literature on bibliographic databases: SCOPUS, WoS, ACM, and ERIC, with the search string: ("Self-Regulated learning" OR "Self-Regulation of Learning") AND ("Immersion" OR "Immersive"). We did not delimit by publication date and only considered peer-reviewed papers in these languages: English, Portuguese, or Spanish. We found 92 papers as potentially relevant (SCOPUS, n = 31; WoS, n = 22; ERIC, n = 6; ACM, n = 33).

Phase 2 - Screening for Inclusion. The 92 papers were screened for inclusion. In a first screen, we analysed titles and abstracts with these inclusion criteria: a) explicitly incorporating the search terms in the abstract: "self-regulated learning" or "self-regulation learning", and "immersion" or "immersive"; b) written in these languages: English, Portuguese, or Spanish; c) all educational contexts and research designs were included. We removed papers that we could not access or found to be duplicated. This excluded 66 papers: a) 27 without both term options; b) 16 without full text; c) 8 papers we could not access, and d) 16 duplicates. This results in 25 papers.

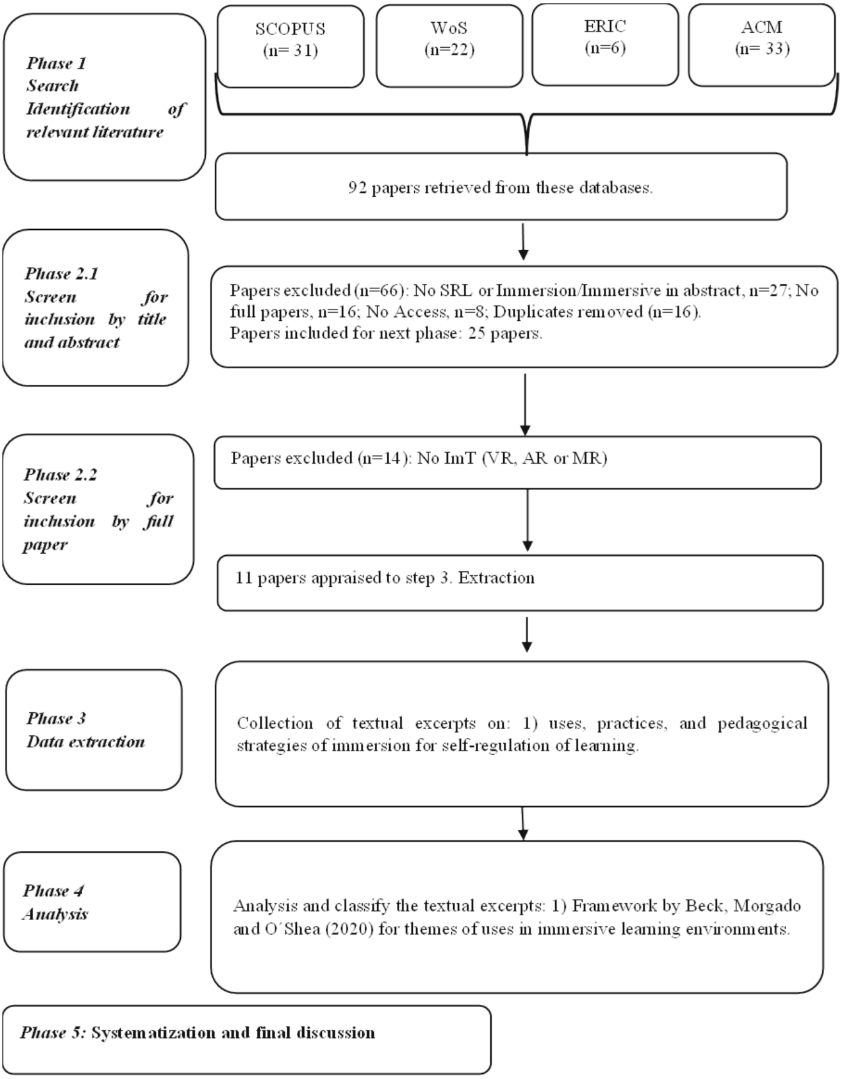

Fig. 1. Work process.

In a second screen, we analysed paper contents entirely, with the inclusion criterium: a) reporting uses of ImT to support SRL. This eliminated 14 papers that did not use these technologies, resulting in 11 papers of review corpus (see Table 1).

Table 1. Corpus of final papers.

ID	Authors	Year	Title
P1	Rahayu & Jacobson	2012	Speaking self-efficacy and English as a foreign language: learning processes in a multi-user
P2	Sakdavong et al.	2019	Virtual Reality in Self-regulated Learning: Example in Art Domain
P3	Chen & Hsu	2020	Self-regulated mobile game-based English learning in a virtual reality environment
P4	Nachtigall et al.	2022	Fostering cognitive strategies for learning with 360° videos in history education contexts
P5	Spiliotopoulos et al.	2019	A Mixed-reality Interaction-driven Game-based Learning Framework
P6	Boomgaard et al.	2022	A Novel Immersive Anatomy Education System (Anat_Hub): Redefining Blended Learning for the Musculoskeletal System
P7	Hayashida et al.	2020	Virtually Alone-How Facilitated Aloneness Affect Self-Study in IVE
P8	Li	2017	Design of Multimedia Teaching Platform for Chinese Folk Art Performance Based on Virtual Reality Technology
P9	Nietfeld et al.	2014	Self-Regulation and Gender Within a Game-Based Learning Environment
P10	Cheng & Tsai	2020	Students' motivational beliefs and strategies, perceived immersion and attitudes towards science learning with immersive virtual reality: A partial least squares analysis
P11	Perera & Allison	2015	Self-Regulated Learning in Virtual Worlds – An Exploratory Study in OpenSim

Phase 3 – Extraction. We collected data by extracting text excerpts from the paper corpus, regarding these aspects:

1) Characterization of the sample (papers) in terms of a) year of publication; b) Study field; c) pedagogical context; d) Research Design; e) Research Sample; f) Duration of study; g) Research Instruments.
2) Descriptions of uses of ImT for SRL (56 text excerpts were extracted).

Phase 4 – Analysis. We conducted descriptive statistical analysis of the studies (goal 1). Regarding the descriptions of uses of VR, AR, or MR (goal 2), we performed thematic content analysis [37], to identify relevant themes. We then employed Beck et al.'s framework to map them to the immersion conceptual space and compare them to overall known uses of ILE [27]. Afterwards, we conducted descriptive statistical analysis to identify their prevalence. Subsequently, a summary was carried out on how each study/paper used ImT for SRL, to illustrate the identified themes.

Phase 5 - Systematization and Final Discussion of Results. We present in the next section the results and discuss about the panorama of uses the ImT to support SRL, and provide recommendations for further work.

4 Results and Discussion

4.1 Characterization of Studies About the Uses of VR, AR, MR for SRL

Years of Publication. Of the 11 papers, studies on VR, AR and MR for SRL are recent: the first paper is from 2012, and interest increased only in the latest 5 years (n = 7) (Fig. 2).

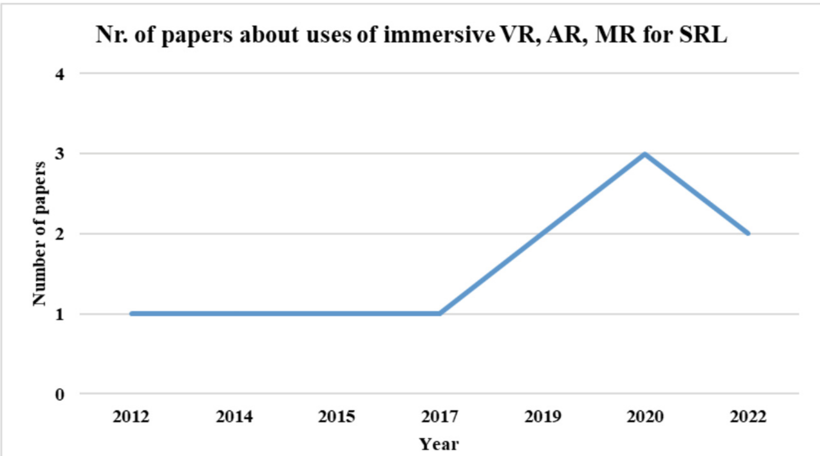

Fig. 2. Evolution of papers about ImT for SRL.

Study Fields. There is variability (Language; Art; Technology; General; Medicine; Biology; History; Social Sciences), with none having a significantly higher prevalence (Fig. 3).

Educational Context. Higher education is predominant (n = 6), with mentions of Basic Education (n = 3), Secondary Education (n = 1), Unspecified (n = 1). There were no studies for preschool education (Fig. 4).

Although the sample of studies is small (n = 11), it demonstrates that the interest in using these technologies to support SRL is increasing, that they are used in various fields, and particularly in Higher Education. Other teaching contexts are fields that deserve to be explored.

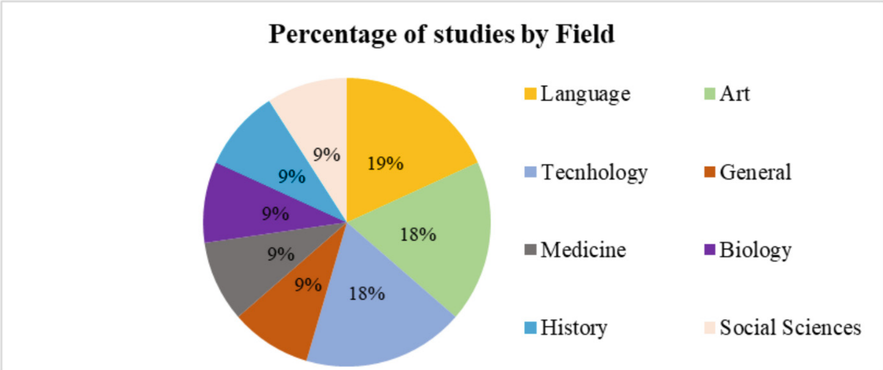

Fig. 3. Study fields.

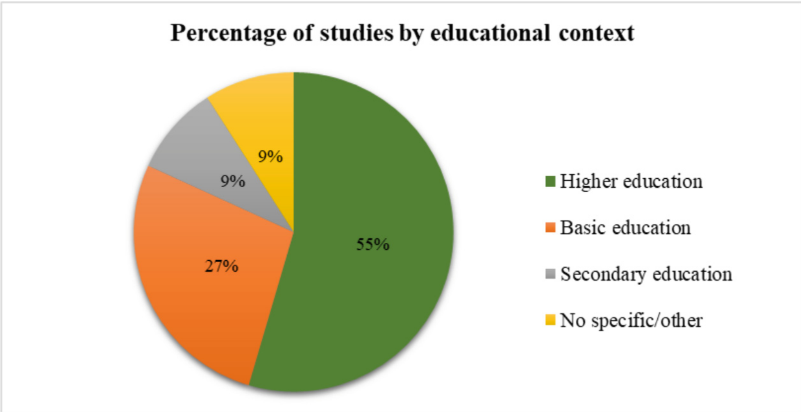

Fig. 4. Educational context.

Research Design. There is a tendency towards experimental or quasi-experimental studies (see Table 2), predominantly using quantitative methods for data analysis.

Table 2. Research design.

Type	Nr. of papers	ID
Experimental	5	P2; P7; P8; P9; P10
Quasi-experimental	2	P3; P4
Case Study	1	P11
Mixed	1	P1
Pilot Study - Participatory design	1	P6
Interactive design	1	P5

Sample. There is a tendency for studies with a sample size below 100 participants (see Table 3).

Duration of Study. The studies are predominantly of a single moment, e.g.: P1; P2; P4; P7; P9; P10; P11; or 2 sessions (e.g., P5). Studies of longer duration were only P3 with a duration of 2 months, and P8 (1 semester). P6 does not mention the duration of intervention.

Table 3. Size sample.

Research Sample	Nr. of papers	ID
<10	1	P1
11 to 50	2	P5; P7
51 to 100	5	P2; P6; P8; P10; P11
101 to 150	1	P9
151 to 200	1	P4
>200	1	P3

Research Instruments for SRL. There is a predominance of quantitative instruments, such as questionnaires and surveys. The dispersion of instruments used is evident, with no common instruments among the studies, which may indicate the need for comparable instruments to evaluate/measure SRL in concert with ImT (Table 4).

4.2 Uses of Immersive VR, AR, MR for SRL

Table 5 shows how the 56 accounts were associated with 18 themes, identifying uses of ImT for SRL [27, 38]. These match 12 of the 16 themes found in Beck et al.'s framework of uses of ILE, and also 1 theme reported in a previous study [38]. Five themes have no matching to previous studies.

In more than half of the papers (n = 7; 63.6%), we found the most prevalent use: "*Interactive manipulation and exploration*", and the same happens in terms of text extracts extracted (17.9%). This use combines these immersion dimensions: High agency and High system. Samples:

> *"(…) familiarization was intended to train the participant, during ten minutes, to use the material and its resources."* Text excerpt from P9.

> *"The students may interactively explore other trees and scenery, trigger wind and rain."* Text excerpt from P5.

The use *"Skill Training"* is the second most prevalent theme, found in almost half of the papers (n = 5, 45.5%) and in 16.1% of the excerpts. It is associated with these immersion dimensions: High agency and Mid-Narrative. Samples:

Table 4. Research instruments for SRL.

Research Instruments for SRL	ID
Questionnaire adapted from Wang (2004) to measure self-efficacy	P1
Interviews about learning habits	P1
Participant observation (DeWalt et al., 98) focused on behaviour & learning process	P1
Questionnaire adapted from Wang (2004) to measure self-efficacy	P1
Adapted questionnaire integrating 2 indicators (time management and metacognition) from Pintrich (2000) and 1 (emotional perception) from Deci et al. (1994)	P2
Game Engagement Questionnaire (GEQ) from Brockmyer et al.'s (2009)	P3
Motivated Strategies for Learning Questionnaire (MSLQ) adapted from Pintrich	P3; P10
Strategy use test (pre- and post-test) on students' cognitive strategies knowledge	P4
Mock-ups to support reflection	P5
Discuss in group	P5
Survey	P6; P8
SDT to measure of intrinsic motivation	P7
Intrinsic Motivation Inventory (IMI)	P7
Measures of cognitive abilities (knowledge and strategy use), self-reported beliefs, trace logs, and measures of calibration	P9
Achievement Goals Questionnaire (AGQ) Scale	P9
Science Learning Self-Efficacy Inventory	P9
Perceived Interest Questionnaire (PIQ)	P9
In-game performance	P9
Immersive Experience Questionnaire (IEQ) from Jennett et al. (2008)	P10
Attitudes survey from Cheng's (2017)	P10
Questionnaire	P11

"SRL training that fostered students' acquisition of cognitive strategies for processing history-related 360° videos (…)" Text excerpt from P4.

"(…) [Crystal Island-Outbreak] students are aware of the overall goal and must successfully navigate through a number of subgoals (…)" Text excerpt from P9.

The uses *"Engagement*" and *"Complement/Combine contexts, media, or items"* also appear in almost half of the analysed papers (45.5%), but with a lower prevalence than previously mentioned themes, with 12,9% and 8.9% respectively. Engagement focuses on high agency immersion, and Complement/Combine in high system immersion. Samples:

Table 5. Uses of VR, AR, and MR for SRL.

Use of ILE	Nr. of papers (n = 11)	Nr. of excerpts (n = 56)	ID papers
Interactive manipulation and exploration	7 (63.6%)	10 (17.9%)	P2 (x2); P3; P5 (x2); P7; P9; P10; P11(x2)
Skill training	5 (45.5%)	9 (16.1%)	P1; P4 (x4); P5; P6; P21 (x2)
Engagement	5 (45.5%)	7 (12.5%)	P1; P3; P5 (x2); P9 (x2); P11
Complement/Combine contexts, media, or items	5 (45.5%)	5 (8.9%)	P4; P5; P6; P10; P11
Collaboration	4 (36.4%)	6 (10.7%)	P1; P4; P5(x3); P10
Simulate the physical world	3 (27.3%)	4 (7.1%)	P1; P2; P3 (x2)
Mobile Learning	2 (18.2%)	4 (7.1%)	P3 (x3); P5
Augmented context	2 (18.2%)	3 (5.4%)	P5 (x2); P10;
Changing human behaviour	2 (18.2%)	2 (3.6%)	P4; P10
Perspective switching	2 (18.2%)	2 (3.6%)	P7; P11
Multimodal interaction	2 (18.2%)	2 (3.6%)	P3; P7
Data collection	1 (9.1%)	1 (1.8%)	P5
Emotional and cultural experiences	1 (9.1%)	1 (1.8%)	P8
LMS	0	0	-
Emphasis	0	0	-
Logistics	0	0	-
Accessibility	0	0	-
Seeing the invisible	0	0	-

"The learning environment (…) showing remaining learning items (progress), hinting or providing gamification-driven bonus feedback to students that explore." Text excerpt from P5 (engagement theme).

"Wireless Island (…) a dedicated region for wireless communication education, (…) lecture notes, lecture media streams and a museum of the history of wireless communication (…)" Text excerpt from P11 (complement theme).

The use "C*ollaboration"* also has some prevalence, found in 4 papers (36.4%) and in 10,7% of text excerpts. It is also associated with high agency immersion. Sample:

"(…) design of collaborative inquiry-based tasks (…)." Text excerpt from P10.

"students (…) share newfound information that they believe that may be of interest to the rest of the learners, and later discuss their rationale on how they chose to learn (paths, logical, deductions, completeness, experience, etc.)." Text excerpt from P15.

Some use themes appear with residual prevalence (7.1% to 1.8%):

Simulate the physical world, e.g.: *"(…) participants attended a class in Second Life with a person's avatar as the teacher (…)"* Text excerpt from P1.

Mobile Learning, for example: *"(…) assigned to study English using a newly created mobile learning app (…)"* Text excerpt from P3.

Augmented context, e.g.: "(…) *adopted the application (app) (…) allows a teacher using a tablet PC (or a smartphone) to broadcast 360° spherical image-based content (…) to his or her students' VR headsets with smartphones."* Text excerpt from P22.

Changing human behaviour, for example: *"(…) fostering students' scientific intrinsic values when learning science with the aid of IVR."* Text excerpt from P10.

Perspective switching, for example: *"Learning aids and content objects in a MUVE are put in-world with specific positions; if students change the terrain shape and land height it can completely change the intended learning experience."* Text excerpt from P11.

Multimodal interaction, e.g.: *"Even though the displayed text changed automatically after every pre-determined time slot, natural use included taking short breaks at any point between task beginning and task end (…)"* Text excerpt from P7.

Data collection, e.g.: *"(…) interaction feedback can be logged and analysed to assess the young users' expectations of the technology (…)*" Text excerpt from P5.

And finally, the use for Emotional and cultural experiences, for example: *"(…) VR-based Chinese folk-art performance (…) was implemented (…) realize interactive learning."* Text excerpt from P8.

Considering the reference framework by Beck et al., some themes were not found identified in the corpus papers, namely: accessibility, logistics, seeing the invisible. These are uses that combine high narrative immersion with significant amounts of system and agency immersion. Thus, we conclude that current uses of ImT to support SRL is leveraging only two of the dimensions of the immersion phenomenon: system-based and challenge-based immersion (see Fig. 5).

Table 6, shows there is a predominant use of VR (n = 6) to support the focus on system immersion, followed by MR (n = 4), AR having less prevalence (n = 1). From the uses of VR, AR, and MR, it appears that the support for the development of SRL is not very explicit and there is little concrete on how learning tasks were designed for students to apply/develop SRL strategies during the planning, execution, and evaluation tasks.

These results confirm that there is a need for further exploration, integration, testing, and creation of instructional design guidelines for immersive experiences in support of SRL [6, 16, 17].

One possible cause for this situation is that the corpus studies are mostly outcome-based experimental, seeking to understanding how such environments affect learning. This tendency towards experimental, quantitative, and applied studies in a single moment, highlights the need to consider research efforts that rather seek to understand

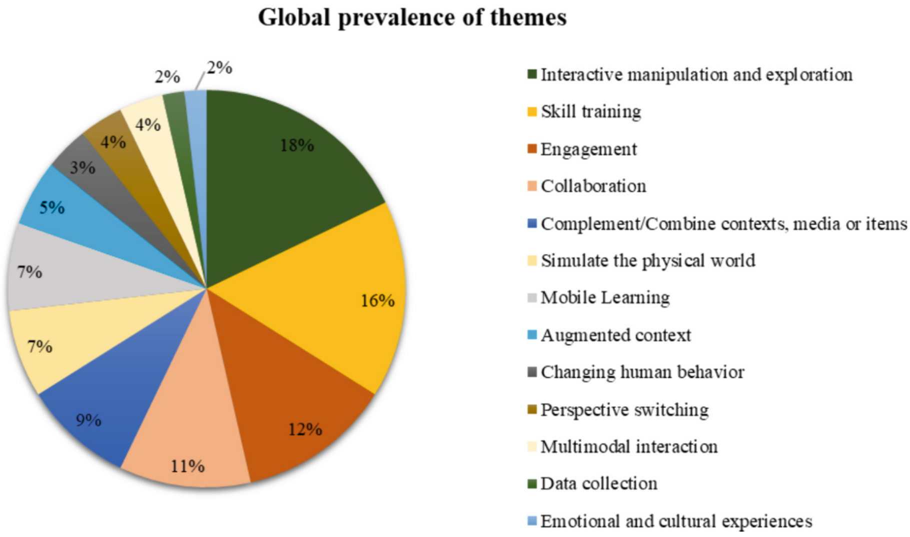

Fig. 5. Prevalence of themes of uses of ImT for SRL.

the possible approaches to support SRL and its different components in immersive environments. Which research methodologies and instruments are suitable to assess/measure SRL in immersive learning is with a question emerging from this work.

Most of the descriptions focus on exploration activities, flexible, free interaction with the environment and resources, self-choices, customizing paths and integration of elements that allow the monitoring of progress, incentive and motivational. This confirms that instructors need to deepen their "know-how" about immersive learning experiences and how to develop different SRL strategies [6, 7, 13, 16, 17].

Table 6. Summary of uses of VR, AR, MR for SRL

ID	Type (VR, AR, or MR)	Description
P1	VR Multi-user virtual environment (MUVE) in Second Life: Language Lab	Virtual English class: Attend a class by a teacher represented by an avatar. Follow the guidelines of tasks and activities. Interaction with other classmates and teacher (avatars). Visit to realistic scenarios. Participation in task of own choice

(*continued*)

Table 6. (*continued*)

ID	Type (VR, AR, or MR)	Description
P2	VR 3D virtual museum and digital environment	Experimentation of 3D spaces to acquire knowledge and use time freely without restrictions. Observation activities and listening information about objects. Conducting a familiarization test (pre-test of knowledge) before taking the actual test. Training to know how to use the material and resources (memory task: memorize knowledge about each virtual sculpture after listening spoken information)
P3	MR Unity + smart mobile device	Freely rotate their bodies to observe from different angles and interact with the content. Content exposed in dialog format. Motivational test items
P4	MR History-related 360° videos	Explicit SRL training to develop cognitive strategies. They learned the terms and functionalities of cognitive and metacognitive strategies. Guidance and practice these strategies to analyse 360º videos through exercises. Use of a digital poster for introduction and class discussion
P5	MR Tablet camera to see their real-life surrounding	Thoughtful paper mock-ups and still screenshots depicting the weather in different outdoor seasons. Items that show progress by providing feedback and rewards for students exploring the environment (incentives). Recording and analysis of feedback to assess expectations. Access to own progress and that of colleagues. Sharing information that you believe will be of interest to others. Discussion of learning options. Flexibility in exploring and interacting with content: choose what you want to learn
P6	AR The Anat_Hub: AR mode, 3D mode; glossary, and quiz features	Interaction with content on information panels. Presentation of contents in an organized way that facilitates the organization and processing of information. Self-tests. Opportunity to choose the format of the material you want to use for the study

(*continued*)

Table 6. (*continued*)

ID	Type (VR, AR, or MR)	Description
P7	VR Whiteboard in the VR space; Head-mounted display (HMD); Voice recognition device (VRD)	Personalized experiences, creating an avatar that reflects the user (physical size and movement). Display of content with automatic change (changes after a while). Control over pause time, so the user can see the content again. Acquisition of phonemes through self-feedback. Access to scores (evaluation)
P8	VR Chinese folk art performance multimedia system	Selection and management of material, instructions, and personal information according to their performance needs
P9	VR Virtual world: Crystal Island-Outbreak	Self-discovery through exploration of the virtual world. Interaction with characters who are experts. Space to formulate questions, generate hypotheses, collect data, and test hypotheses. Completion and submission of a diagnosis. Provision of score (feedback) with reward for having efficiently reached the objectives. Awareness of the overall goal. Solving complex problems
P10	MR VR headsets with smartphones	Collaborative activities to promote scientific intrinsic values. Content transmission. Exploration of virtual spaces. Scene observation, synchronization, and activation of instructions for acquiring detailed information. Resource involvement
P11	VR OpenSim: Wireless Island	Interactive simulations. Exploration of learning contents. Experimentation with constructions and can edit objects. Learning materials available at specific locations

5 Limitations

This literature review had one specific focus and consequently only included papers explicitly mentioning the terms “self-regulated learning” and “immersion” in their abstracts. So, papers that worked on SRL or immersion by other terms may have been excluded. Also, the final corpus is small, so results generalization is limited. We recommend that future literature reviews include other search terms related to SRL and VR, AR, MR. In addition, we recommend considering SRL more broadly, by considering not only SRL wholly, but also the individual SRL strategies (e.g., time management, seeking help, monitoring, etc.).

6 Conclusions and Final Thoughts

This work showed that uses of VR, AR, and MR to support the development of SRL has increased in recent years, in various fields and mostly in higher education, but also in other contexts. We identified 18 uses, 5 of which are not found in the reference framework. They were also found to be absent in combination of high narrative immersion with significant levels of system-based and agency-based immersion. Despite this interest and increased use, explicit details of the instructional design and implementation of the found uses to develop SRL strategies are vague, focusing essentially on flexibility, freedom of self-exploration, interaction, manipulation of spaces and resources, feedback elements, and motivational approaches.

The studies lack details on how to support development of SRL strategies (such as planning, managing, seeking help, transformation, review, self-assessment, etc.). This points towards opportunities to explore these uses and describe them to support replication and application studies. There is also a clear need to study the applicability to SRL of uses of immersive environments associated with high narrative immersion that integrates significant levels of the other dimensions the phenomenon of immersion.

Acknowledgment. This work is financially supported by National Funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., under the project UIDB/00194/2020. D. Pedrosa wishes to thank FCT and CIDTFF - Universidade de Aveiro, Portugal, for Stimulus of Scientific Employment – CEECIND/00986/2017 Individual Support 2017.

References

1. 2020 EDUCAUSE Horizon Report: Teaching and Learning Edition. EDUCAUSE (Association), Louisville, CO [USA] (2020)
2. Suh, A., Prophet, J.: The state of immersive technology research: a literature analysis. Comput. Hum. Behav. **86**, 77–90 (2018). https://doi.org/10.1016/j.chb.2018.04.019
3. Bekele, M.K., Pierdicca, R., Frontoni, E., Malinverni, E.S., Gain, J.: A survey of augmented, virtual, and mixed reality for cultural heritage. J. Comput. Cult. Herit. **11**, 7:1–7:36 (2018). https://doi.org/10.1145/3145534
4. Guo, X., Guo, Y., Liu, Y.: The development of extended reality in education: inspiration from the research literature. Sustainability. **13**, 13776 (2021). https://doi.org/10.3390/su132413776
5. Tang, Y.M., Chau, K.Y., Kwok, A.P.K., Zhu, T., Ma, X.: A systematic review of immersive technology applications for medical practice and education - trends, application areas, recipients, teaching contents, evaluation methods, and performance. Educ. Res. Rev. **35**, 100429 (2022). https://doi.org/10.1016/j.edurev.2021.100429
6. Makransky, G., Mayer, R.E.: Benefits of taking a virtual field trip in immersive virtual reality: evidence for the immersion principle in multimedia learning. Educ. Psychol. Rev. **34**, 1771–1798 (2022). https://doi.org/10.1007/s10648-022-09675-4
7. Pellas, N., Mystakidis, S., Kazanidis, I.: Immersive virtual reality in K-12 and higher education: a systematic review of the last decade scientific literature. Virtual Real. **25**, 835–861 (2021). https://doi.org/10.1007/s10055-020-00489-9
8. Garzón, J., Pavón, J., Baldiris, S.: Systematic review and meta-analysis of augmented reality in educational settings. Virtual Real. **23**, 447–459 (2019). https://doi.org/10.1007/s10055-019-00379-9

9. Akçayır, M., Akçayır, G.: Advantages and challenges associated with augmented reality for education: a systematic review of the literature. Educ. Res. Rev. **20**, 1–11 (2017). https://doi.org/10.1016/j.edurev.2016.11.002
10. Crompton, H., Bernacki, M., Greene, J.A.: Psychological foundations of emerging technologies for teaching and learning in higher education. Curr. Opin. Psychol. **36**, 101–105 (2020). https://doi.org/10.1016/j.copsyc.2020.04.011
11. Makransky, G., Petersen, G.B.: The cognitive affective model of immersive learning (CAMIL): a theoretical research-based model of learning in immersive virtual reality. Educ. Psychol. Rev. **33**, 937–958 (2021). https://doi.org/10.1007/s10648-020-09586-2
12. Kaplan, A.D., Cruit, J., Endsley, M., Beers, S.M., Sawyer, B.D., Hancock, P.A.: The effects of virtual reality, augmented reality, and mixed reality as training enhancement methods: a meta-analysis. Hum. Factors **63**, 706–726 (2021). https://doi.org/10.1177/0018720820904229
13. Dunleavy, M., Dede, C., Mitchell, R.: Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. J. Sci. Educ. Technol. **18**, 7–22 (2009). https://doi.org/10.1007/s10956-008-9119-1
14. Makransky, G., Wismer, P., Mayer, R.E.: A gender matching effect in learning with pedagogical agents in an immersive virtual reality science simulation. J. Comput. Assist. Learn. **35**, 349–358 (2019). https://doi.org/10.1111/jcal.12335
15. Makransky, G., Terkildsen, T.S., Mayer, R.E.: Adding immersive virtual reality to a science lab simulation causes more presence but less learning. Learn. Instr. **60**, 225–236 (2019). https://doi.org/10.1016/j.learninstruc.2017.12.007
16. Pirker, J., Dengel, A., Holly, M., Safikhani, S.: Virtual reality in computer science education: a systematic review. In: Proceedings of the 26th ACM Symposium on Virtual Reality Software and Technology, pp. 1–8. Association for Computing Machinery, New York (2020)
17. Wagner, C., Liu, L.: Creating Immersive Learning Experiences: A Pedagogical Design Perspective. In: Hui, A., Wagner, C. (eds.) Creative and Collaborative Learning through Immersion, pp. 71–87. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-72216-6_5
18. Pintrich, P.R.: A conceptual framework for assessing motivation and self-regulated learning in college students. Educ. Psychol. Rev. **16**, 385–407 (2004). https://doi.org/10.1007/s10648-004-0006-x
19. Zimmerman, B.J.: From cognitive modeling to self-regulation: a social cognitive career path. Educ. Psychol. **48**, 135–147 (2013). https://doi.org/10.1080/00461520.2013.794676
20. Panadero, E.: A review of self-regulated learning: six models and four directions for research. Front. Psychol. **8**, 422 (2017). https://doi.org/10.3389/fpsyg.2017.00422
21. Pedrosa, D., Cravino, J.P., Morgado, L. (eds.): e-SimProgramming: planificar, conceber e acompanhar atividades didáticas online de engenharia de software. Universidade Aberta, Lisboa, Portugal (2022)
22. Broadbent, J., Poon, W.L.: Self-regulated learning strategies & academic achievement in online higher education learning environments: a systematic review. Internet High. Educ. **27**, 1–13 (2015). https://doi.org/10.1016/j.iheduc.2015.04.007
23. Kramarski, B., Heaysman, O.: A conceptual framework and a professional development model for supporting teachers' "triple SRL–SRT processes" and promoting students' academic outcomes. Educ. Psychol. **56**, 298–311 (2021). https://doi.org/10.1080/00461520.2021.1985502
24. Dengel, A.: What is immersive learning? In: 2022 8th International Conference of the Immersive Learning Research Network (iLRN), pp. 1–5 (2022)
25. Nilsson, N.C., Nordahl, R., Serafin, S.: Immersion revisited: a review of existing definitions of immersion and their relation to different theories of presence. Hum. Technol. **12**, 108–134 (2016). https://doi.org/10.17011/ht/urn.201611174652

26. Agrawal, S., Simon, A., Bech, S., Bærentsen, K., Forchhammer, S.: Defining immersion: literature review and implications for research on audiovisual experiences. J. Audio Eng. Soc. **68**, 404–417 (2020). https://doi.org/10.17743/jaes.2020.0039
27. Beck, D., Morgado, L., O'Shea, P.: Finding the gaps about uses of immersive learning environments: a survey of surveys. J. Univers. Comput. Sci. **26**(8), 1043–1073 (2020)
28. Maas, M.J., Hughes, J.M.: Virtual, augmented and mixed reality in K–12 education: a review of the literature. Technol. Pedagogy Educ. **29**, 231–249 (2020). https://doi.org/10.1080/1475939X.2020.1737210
29. Milgram, P., Kishino, F.: A Taxonomy of Mixed Reality Visual Displays. https://search.ieice.org/bin/summary.php?id=e77-d_12_1321
30. Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., Ivkovic, M.: Augmented reality technologies, systems and applications. Multimed. Tools Appl. **51**, 341–377 (2011). https://doi.org/10.1007/s11042-010-0660-6
31. Flavián, C., Ibáñez-Sánchez, S., Orús, C.: The impact of virtual, augmented and mixed reality technologies on the customer experience. J. Bus. Res. **100**, 547–560 (2019). https://doi.org/10.1016/j.jbusres.2018.10.050
32. Rauschnabel, P.A., Felix, R., Hinsch, C., Shahab, H., Alt, F.: What is XR? towards a framework for augmented and virtual reality. Comput. Hum. Behav. **133**, 107289 (2022). https://doi.org/10.1016/j.chb.2022.107289
33. Skarbez, R., Smith, M., Whitton, M.C.: Revisiting milgram and Kishino's reality-virtuality continuum. Front. Virtual Real. **2** (2021)
34. Pan, Z., Cheok, A.D., Yang, H., Zhu, J., Shi, J.: Virtual reality and mixed reality for virtual learning environments. Comput. Graph. **30**, 20–28 (2006). https://doi.org/10.1016/j.cag.2005.10.004
35. Hughes, C.E., Stapleton, C.B., Hughes, D.E., Smith, E.M.: Mixed reality in education, entertainment, and training. IEEE Comput. Graph. Appl. **25**, 24–30 (2005). https://doi.org/10.1109/MCG.2005.139
36. Kitchenham, B.A., Budgen, D., Brereton, P.: Evidence-Based Software Engineering and Systematic Reviews. Chapman & Hall/CRC (2015)
37. Braun, V., Clarke, V.: Using thematic analysis in psychology. Qual. Res. Psychol. **3**, 77–101 (2006). https://doi.org/10.1191/1478088706qp063oa
38. Pedrosa, D., Morgado, L., Beck, D.: Companion dataset for paper "Immersive Learning Environments for Self-Regulation of Learning: A Literature Review" (2023). https://zenodo.org/record/7568158