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Ambienti sociali di apprendimento sostenuti dalle tecnologie digitali, sviluppo delle competenze e nuovi profili dei formatori

Using Augmented and Virtual Reality for teaching scientific disciplines

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ABSTRACT

This paper aims at synthesizing the literature on the use of AR and VR for teaching scientific disciplines to identify strengths and weaknesses for student's learning. Articles published in peer reviewed journals has been searched on Google Scholar from 2018. The results highlighted a great variety of studies' methodology, field of applications, technology, target groups and outcomes. The growing interest in this topic is due to the emerging benefits for learning achievements, attitudes and motivations. Further studies are necessary to understand the type of technologies to be used in different contexts and to focus on learners' characteristics, and its impact on learning outcomes. It is necessary to improve students' and teachers' digital competence, supporting them in designing educational intervention for the acquisition of scientific skills.

SINTESI

Questo contributo ha l'obiettivo di sintetizzare le evidenze esistenti circa l'utilizzo della realtà aumentata e della realtà virtuale per l'insegnamento delle discipline scientifiche, al fine di identificare punti di forza e aspetti critici per l'apprendimento. La ricerca è stata condotta su Google Scholar, selezionando gli articoli pubblicati in riviste scientifiche *peer reviewed* dal 2018 ad oggi. Gli articoli analizzati mostrano una grande eterogeneità di metodologie, campi di applicazione, tecnologie e risultati. Il crescente interesse in questo campo di applicazione è dovuto ai benefici ottenuti in termini di apprendimento, attitudine e motivazione. Ulteriori ricerche sono necessarie per comprendere quali tecnologie utilizzare, in differenti contesti e a seconda delle caratteristiche degli studenti, e valutarne l'impatto sui risultati di apprendimento. Allo stesso tempo, è necessario migliorare le competenze digitali di studenti e insegnanti, supportandoli anche nella progettazione di interventi educativi per l'acquisizione di competenze scientifiche.

KEYWORDS: science teaching, augmented reality, virtual reality, digital learning, innovative teaching

PAROLE CHIAVE: insegnamento delle scienze, realtà aumentata, realtà virtuale, apprendimento digitale, insegnamento innovativo

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Introduction

The integration of digital technologies in teaching and learning practices is increasingly becoming fundamental for education, as also demonstrated by the current pandemic period that forcefully led to the adoption of remote teaching at all school levels. Among innovative practices for teaching and learning the use of the so called X-Reality, a general term encompassing Augmented Reality (AR), Virtual Reality (VR) and 2D/3D Videos, to enhance student's learning seems very promising (Ranieri et al., 2020; Chavez et al., 2018; Jensen et al., 2018; Radianti et al., 2020), particularly referring to scientific disciplines, where these tools appear to be suitable for improving the acquisition of scientific skills and increasing the interest in science (Ibanez et al., 2018). Indeed, the inclusion of the visual component in teaching scientific concepts or phenomena, that cannot be easily explored in classes, are more effective than traditional teaching methods (Arici et al., 2019).

A particularly promising technology is the Augmented Reality (AR), enabling student's activity (Arici et al., 2019) within an individual learning environment based on the combination of «the physical and digital worlds in real time» (Ibanez et al., 2018, p. 2). In science education, AR provides positive results regarding conceptual understanding (Ibanez et al., 2018). The Virtual Reality (both conducted with 2D/3D videos) has the great benefit of permitting a full and direct interaction with environments hardly to be visited in person for the students with or without the guidance of the teacher (e.g. a surgery, an archeological site) (Reeves et al., 2020) or to observe invisible phenomena, as the work inside a cell, the physics concept, or the consequence of ocean acidification for marine ecosystems (Markowitz, et al., 2018; Fidan et al., 2019; Makransky et al., 2020).

The same positive effects have been described for the use of these technologies in fully immersive environments, although actual applications in education are at the beginning and only preliminary results have been reported (Chavez et al., 2018; Jensen et al., 2018; Radianti et al., 2020). Furthermore, a systematic review – in the educational domain but not specifically related to science education – by Jensen et al. (2018) explored the usefulness of Head Mounted Displays (HMDs) for skills acquisition in education and training. HMDs offered some advantages for remembering and understanding visual and spatial dimensions (cognitive skills), visual scanning or observational skills (psychomotor skills), controlling emotional response to stressful or difficult situations (affective skills). Out of these categories, HMDs do not offer any additional advantages, being in some cases counterproductive due to the physical discomfort (Jensen et al., 2018) caused by the so called cybersickness. Moreover, most articles focus more on the usability of the tools than on the learning outcomes (Chavez et al., 2018; Jensen et al., 2018; Radianti et al., 2020) or scientific knowledge and skills acquisition (Reeves et al., 2020). This paper aims at exploring and synthesizing the literature on the use of AR and VR for teaching scientific disciplines in order to identify the main strengths and weaknesses of this approach for student's learning. In the first part of the paper, the methodology and the sample studies are described, while in the second part the results are presented and discussed.

1. Methods

The search has been conducted on Google Scholar combining the following keywords: “science education”, “science learning”, “virtual reality”, “augmented reality”. In the analysis, we included research articles dated from 2018 up to date. Since technological tools and their applications rapidly evolved, we decided to focus on the most recent literature findings, to avoid misleading observations due to the fast-changing technology-driven scenario. Further inclusion criteria were: research articles published in peer-review journals, including systematic reviews, written in English, dealing with the use of AR and VR for science education at all the school levels and higher education. Reflections papers, grey literature, handbooks, practical papers have been excluded. Titles and abstracts have been screened firstly, then the full texts have been examined. Reference lists of the selected articles have been also screened to identify further publications.

The full articles have been analysed in order to extract information about the study design, the technologies used, the scientific fields, the target group, duration, the measured outcomes, the main results, and the learners’ and teachers’ reaction.

The search identified 989 articles and after the screening of titles and abstracts, 23 papers have been selected (of which 6 do not have the full text available). Thus, 17 papers have been examined: 9 are published in 2020, 5 in 2019 and 3 in 2018; 3 are systematic reviews (Reeves et al., 2020; Arici et al., 2019; Ibanez et al., 2018) and 14 are empirical articles (Sahin et al., 2020; Salar et al., 2020; Weng et al., 2020; Chen, 2020; Cheng et al., 2020; Makransky et al., 2020; Beyoglu et al., 2020; Madden et al., 2020; Fidan et al., 2019; Klippel et al., 2019; Weng et al., 2019; Huang et al., 2019; Lamb et al., 2018; Markowitz et al., 2018) (see Table 1).

The results of the articles identified, including the systematic reviews, are summarized in the paragraph below.

Year	Empirical articles	Systematic Review
2020	Sahin et al.; Salar et al.; Weng et al.; Chen; Cheng et al.; Makransky et al.; Beyoglu et al.; Madden et al.	Reeves et al.
2019	Klippel et al.; Weng et al.; Huang et al.	Arici et al.
2018	Lamb et al.; Markowitz et al.	Ibanez et al.

N° of articles	14	3

TABLE 1 – LITERATURE REVIEW RESULTS

1.1. Research Questions

The specific research questions which guided the search of literature on the use of AR and VR in science education are:

RQ1: what are the main characteristics of the studies identified, particularly referring to the technology use, the target group, the study design, the subject, the duration?

RQ2: what are the measured outcomes, main results, benefits, drawbacks related to the use of AR and VR for teaching scientific disciplines?

2. Results

2.1. RQ1: what are the main characteristics of the studies identified, particularly referring to the technology use, the target group, the study design, the subject, the duration?

Technology use: seven out of 17 papers used AR technology, 6 used VR, 2 used both AR and VR, with one comparing AR against VR, and the other comparing VR versus Serious Educational Games (SEGs).

Target group: the articles analysed in the review by Ibanez et al. (2018) deals with studies focusing on middle schools and higher education students. The main targets addressed in Arici et al. (2019) are primary students (5–8th grade) in 19 out of 62 articles, followed by 14 out of 62 studies involving primary students (1–4th grade), 13 out of 62 articles graduate students, 10 out of 62 articles secondary students (9–12th grade). Reeves et al. (2020) focus on undergraduate students. In the 14 empirical articles, 8 studies involved primary students (from 4th to 9th grade), 6 involved university students and 2 involved high school students.

Studies Design: the review by Ibanez et al. (2018) reported that the most represented study design type in the articles they examined, is Quantitative Design (13 out of 28 articles), followed by Mixed Design (10 out of 28 articles) and Qualitative Design (5 articles). In the review by Arici et al. (2019), most articles have a Quantitative Design (81% of 62 articles) followed by Mixed Design (10% of 62 articles), Meta-analysis/Review (6% of 62 articles), and Qualitative Design (3% of 62 articles). Moving to the empirical articles, 8 out of 14 articles adopted Quantitative Design (4 experimental, 2 pre-post, 1 correlational and 1 quasi experimental design) and 5 out of 14 used Mixed Methods (2 quasi experimental design + interviews, 3 experimental design + interviews), see Table 2.

Duration of educational intervention: Ibanez et al. (2018) found that most of the studies focuses on educational interventions that took place in a unique session (from 7 to 180 min), followed by interventions lasting up to 18 weeks. Moving to the empirical experimental articles, the majority (8 out 14 articles) describe educational interventions in a unique session, from 12 minutes to 80 minutes, while 3 studies described studies that lasted from 4 weeks to 11 weeks. Three articles did not include this information.

Authors	X-Reality type	Target Group and Study Design	Duration
Reeves et al., 2020	VR	Undergraduate students	-
Arici et al., 2019	AR	Primary students (5–8th grade) in 19 out of 62 articles, 14 out 62 studies involving primary students (1–4th grade), 13 out of 62 articles graduate students, 10 out of 62 articles secondary students (9–12th grade) Quantitative Design (81% of 62 articles), Mixed Design (10% of 62 articles), Meta-analysis/Review (6% of 62 articles), Qualitative Design (3% of 62 articles)	-
Ibanez et al., 2018	AR	Middle schools and higher education students Quantitative Design (13 out of 28 articles), Mixed Design (10 out of 28 articles) and Qualitative Design (5 articles)	From 7 to 180 min
Sahin et al., 2020	AR	100 college students (mean age 18.4y) Quasi-experimental study 1) lesson with AR, 2) traditional methods	4 weeks (16 h)
Salar et al., 2020	AR	180 preservice teachers Correlational design	2h
Weng et al., 2020	AR	68 9th-grade students Quasi-experimental design 2 groups: 1) printed book + AR, 2) control group, printed book alone	45 min
Chen, 2020	AR	100 students' 4th grades (mean age 9.5 y) two-factor experimental design 1) AR-G group, 2) AR-N group, 3) N-G group, 4) N–N group	80 min

Cheng et al., 2020	VR	76 5th grade (age 10 to 11y) Not specified	30 min
Makransky et al., 2020	VR	2 studies 99 7th and 8th grade students (13-16 y) 1 pre/post test design 131 2nd and 3rd high school students (aged 17-20y) 2 experimental design: 1) low/high immersive VR, 2) video simulation	Study 1: 15 and 20 min Study 2: 12 min
Beyoglu et al., 2020	AR and VR	42 5th grade (age 11y) experimental study 2 groups: 1) MX, 2) traditional methods	8 weeks (3 days a week; 40 min per lessons)
Madden et al., 2020	VR	172 undergraduate students (age 18-24y) between-subjects pre-post design 1) hands-on activity, 2) VR, 3) desktop simulation	-
Fidan et al., 2019	AR	917th grades junior high school students (age 12- 14y) Quasi-experimental study, 3 groups: 1) problem-based learning (PBL)-AR to teach the subjects of physics, 2) PBL alone, 3) no intervention	11 weeks 5–9 h per week.
Klippel et al., 2019	VR	44 students (mean age for each group 19.4 and 19.9y) Experimental study 2 groups: 1) experiencing a traditional field trip, 2) VR field trip	40 min
Weng et al., 2019	AR and VR	80 5th grade students (age 9-11y) Experimental study 2 groups: 1) printed book + MR, 2) control group, printed book only (in each group participants were separated in high and low spatial ability)	30 min

Huang et al., 2019	AR compared to VR	109 university's students experimental design (57 in the AR condition and 52 in the VR condition)	-
Lamb et al., 2018	VR compared to SEGs	100 college students (mean age 18.40y) Experimental study 4 groups (25 students): 1) video lecture, 2) SEG (in a PBL model), 3) VR, 4) hands-on activity	Video Lecture: 20 min; VR: mean 18,40 min; SEGs: 21.10 min Hands-on activities: 13.80
Markowitz et al., 2018	VR	19 high school students (age 16-18y) Experimental study 1) VR groups, 2) assignments at desk	-

TABLE 2 – TECHNOLOGICAL FEATURES AND STUDY DESIGN OF ANALYSED PAPERS

Lesson's topic: in Ibanez et al. (2018), the majority of AR learning activities are in the field of Physics, followed by Mathematics and Life Science. In Arici et al. (2019) the topic of the lesson much addressed are Science (without any other specifications) (34 out of 62 articles), followed by Biology (15 out of 62 articles), Physics (6 out of 62 articles), Astronomy, Chemistry, Biochemistry (respectively, 2, 2, and 1 out of 62). In Reeves et al. the topic most addressed in the virtual laboratories is Biology (4 out of 25 articles), Biotechnology (3 out of 25 articles), Cellular and Microbiology (3 out of 25 articles) followed by Chemistry (2 out of 25 articles). In the empirical studies, the most represented topic are Astronomy (solar system, space concepts, moon phases,...) (5 out of 14 articles) and Biology (DNA analysis, replication, cell and molecular structure, food) (5 out of 14 articles), followed by Natural Science (animals, environment, climate change) (3 out of 14 articles), Solar Photovoltaic panel (1 out of 14 articles), Laboratory safety (1 out of 14 articles), Earth science (1 out of 14 articles), Physics (1 out of 14 articles), as summarized in Figure 1.

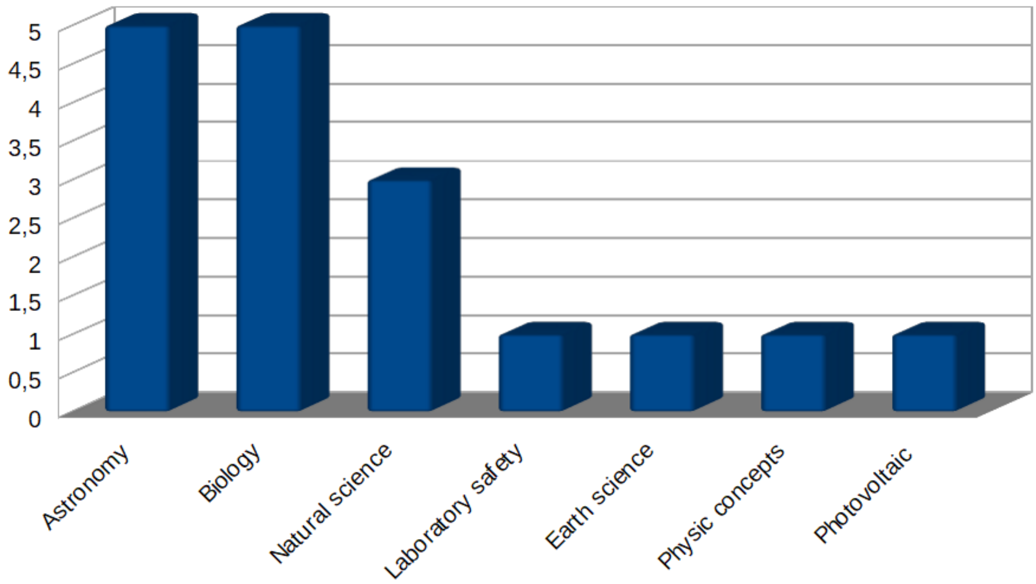

FIGURE 1 – TOPIC OF LESSONS IN THE EMPIRICAL ARTICLES

2.2. RQ2: what are the measured outcomes, main results, benefits, drawbacks related to the use of AR and VR for teaching scientific disciplines?

Outcome measures: concerning the measured outcomes in Ibanez et al. (2018), the most investigated are the motivation (7 articles), followed by attitudes (5 articles), enjoyment (4 articles) and engagement (4 articles) in the sphere of emotional aspects, while in the cognitive one the ability to remember information is the most common factor examined (18 articles). In Arici et al. (2019), the main measured outcomes are learning/academic achievement (32 out of 62 articles), motivation (12 out of 62 articles) and attitude (9 out of 62 articles). The most used outcome measure in the 25 articles described in the Reeves et al. (2020) analysis are: knowing and understanding (15 articles) and perception (12 articles). In the 14 empirical articles, the frequency of outcome measures are learning/academic achievement (9 articles), attitude toward AR and VR (5 articles), attitude toward the subject (5 articles), presence/immersion level (5 articles), learning motivation (2 articles), spatial ability (2 articles), long term retention of knowledge (2 articles), students' self- efficacy (2 articles), see Figure 2. These have been investigated through questionnaires, tests, surveys, written assignments, multiple choice questions. Furthermore, 5 articles used interviews to deeply investigate student's perception on learning activities, students' view of AR and VR.

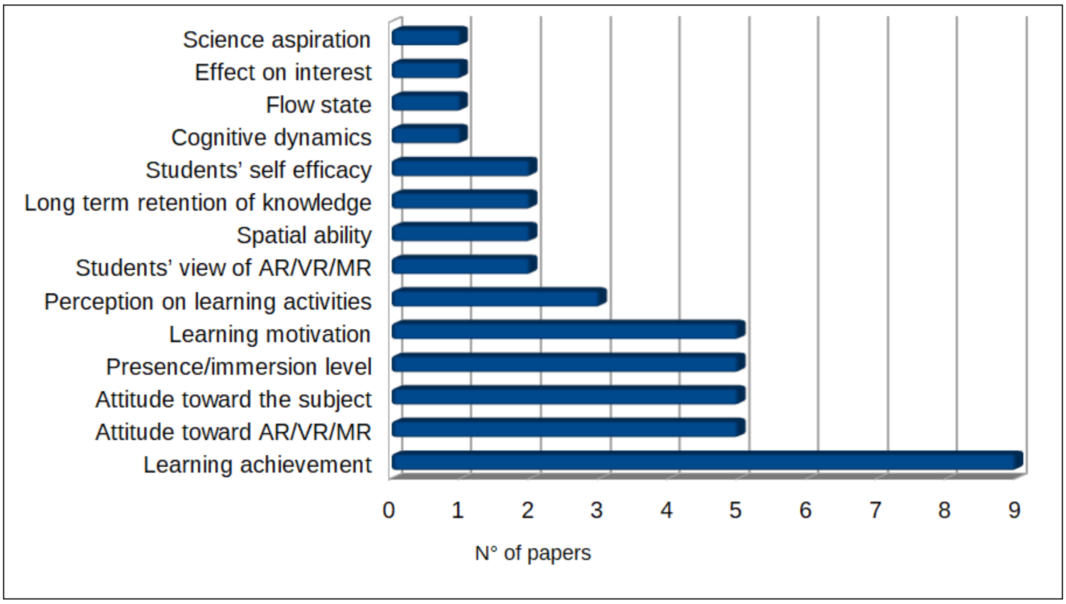

FIGURE 2 – FREQUENCY OF OUTCOME MEASURES IN EMPIRICAL ARTICLES

Teaching methodologies: in Ibanez et al. (2018), the most used teaching methods is the observation (14 out of 28 articles), inquiry (10 out of 14 articles), game (2 out of 14 articles), role-play (1 out of 14 articles) and concepts maps (1 out of 14 articles). The review by Reeves et al. (2020) focused on teaching science through virtual laboratories. In the 14 empirical papers the most used teaching methods are laboratory simulations (3 out of 14 articles), field trips (3 out of 14 articles) followed by Problem-Based Learning (PBL) (2 out of 14 articles) and game based (1 out of 14 articles).

Main results and benefits: Ibanez et al. (2018) described the use of AR in STEM (Science, Technology, Engineering and Mathematics) learning at all school levels, highlighting the need to allow students to acquire STEM basic competences, to provide metacognitive scaffolding and experimental support for inquiry-based learning activities, and to explore how augmented reality learning activities can be part of blended instructional strategies. Arici et al. (2019) summarized the research trends using AR in science education at all school levels over a period of 6 years, underlined some suggestions for further studies derived from articles analysis, as to focus much more on cognitive issues, interaction and collaborative activities, to include other target groups as pre-school students and students with disabilities to integrate qualitative research methodologies. The review by Reeves et al. (2020) reported positive outcomes with virtual laboratories for science learning in undergraduate students, which yet might be related more to the novelty of the approach. The 14 empirical articles reported interesting results using X-Reality for science teaching. Regarding the 5 articles that described the use of AR in science education (Fidan et al., 2019; Sahin et al., 2020; Salar et al., 2020; Weng et al., 2020; Chen, 2020) promising results have been reported: Fidan et al. (2019) investigated the effect of the combination of AR and PBL on 7th grades school students, showing an increase in students' learning achievement and attitude towards physics, with respect to the separate use of AR and PBL alone, together with a long term retention of knowledge, up to 3 weeks from the end of the educational intervention have been shown. Similarly, Sahin et al. (2020) investigate the use of AR for a Solar System lesson on 7th grades school students. Higher levels of learning achievement and positive attitude toward the course have been demonstrated compared to the control group (traditional teaching methods), also revealing the low level of students' anxiety during AR use. In the correlational study, Salar et al. (2020) aimed at studying the relationship between interest, usability, emotional investment, focus of attention, presence, and flow among university students using AR for a lesson on molecular and cellular structure and planets. It emerged that emotional investment and presence of students influenced their attention, while usability and emotional investment influenced their interest. Positive results have been reported by Weng et al. (2020) using the AR integrated into the print book for biology learning of 9th-grade school students. AR technology enhances students' learning outcomes considering the analytical dimension (not the remembering and understanding level) and their attitude toward the course, also confirmed by the students' interviews. Chen (2020) described the implementation of an AR game-based learning method for a natural science course with 4th grade students. The results showed that no significant interactive effects of AR and the digital game have been detected. Although both AR and digital games increase students' learning motivation, only the digital games enhance learning achievements and flow state.

Also, for VR the six articles (Lamb et al., 2018; Markowitz et al., 2018; Klippel et al., 2019; Makransky et al., 2020; Cheng et al., 2020; Madden et al., 2020) reported positive results in science education. Lamb et al. (2018) compared the use of VR, video lecture, Serious Educational Games and hands-on activities to investigate the difference between these approaches in cognitive dynamics, through the analysis of hemodynamic response. One-hundred college students have been involved in learning activities on DNA replication, reporting any significant difference in learning outcomes and cognitive processing. The first study presented in Markowitz et al. (2018) reported the results about the VR field trip to see the accelerated effects of ocean acidification in a high school class, describing an increase on students' learning gains from pre-test phase to post-test. Similarly, Klippel et al. (2019) described an experience in geoscience class of University's students, showing superior advantages of a VR trip in students' enjoyment, learning experience and laboratory scores with respect to the usual site visits (Klippel et al., 2019). The same positive results on VR field trip have been reported by Cheng et al. (2020) in the field of solar photovoltaic power plant in a science class of elementary school. The study revealed that students' motivational characteristics and their perceived immersion were associated. In this context, the intrinsic value and self-regulation for science learning could positively predict their perceived immersion. Moreover, it showed that students with lower levels of self-efficacy may have been more immersed in VR environments and further held positive learning attitudes.

Makranski et al. (2020) described the experience of using VR to increase the interest and career aspiration in 19 7th and 8th grade school and 47 high school students. The 2 studies have been designed on the themes of laboratory safety and DNA analysis, respectively. The results showed that in study 1, VR simulation increased the science aspiration, particularly in female students that reached the same aspiration level as males. Moreover, it also increased the student's self-efficacy. In the second study, Makranski et al. (2018) showed higher learning gain after VR simulation with respect to the use of video alone.

Madden et al. (2020) showed that VR for Moon phase teaching did not provide any advantages compared to hands-on activities and desktop simulation in 172 undergraduate students. However, considering the gender, some differences between conditions have been detected with higher performance likely correlated with more experience with video games correlated with video games experience.

Some studies described the use of both AR and VR for science education: Weng et al. (2019) integrated AR and VR in a science book to improve learning outcomes in 5th grades school students on solar and lunar eclipses compared to traditional science books. AR and VR helped in improving students' learning outcomes in remembering, analysing and understanding, especially in students with low spatial ability. Finally, Beyoglu et al. (2020) demonstrated that X-Reality can be effective in motivating elementary students for collaborative work in science learning, although they did not show any differences in motivation towards research, performance, communication, participation, and learning. Furthermore, the students' interviews provided the evidence that they are pleased to use AR and VR for science learning.

Finally, only 1 study (Huang et al., 2019) compared the use of AR and VR for science knowledge retention about the solar system on university students. The results of the study underlined that VR is more immersive and engaging due to the sense of presence, thus may be more effective in vehiculating educational content that requires visual information, while when the information is related to auditory modalities, the AR is the more appropriate approach.

Drawbacks: the experimental papers reported some drawbacks in using the X-Reality approach for science learning, that can be classified into those related to the students' physical discomfort or to technical problems. Under the technological dimension, Ibanez et al. (2018) reported delayed feedback, slow systems and not intuitive interfaces. Moreover, the student distraction has been also documented, may be due to the novelty effect of the AR integration into teaching and learning.

Cheng et al. (2020) described that during the use of VR, students did not continuously wear the headset due to the dizzying effect of the virtual trip. Similarly, Fidan et al. (2019) described problems with eyes, arms, and hand pain because of holding tablets. At the same time, students experienced technical problems with the app used, since it ran slowly. Weng et al. (2019) described some difficulties related to the scanning of markers in AR, due to the slow response of the camera. Furthermore, Markowitz et al. (2018) underlined a particular problem related to the perception of the outside world during the VR experience. In fact, it has been reported that, during the VR experience, the students not involved were taking pictures of their peers using the VR HMD. Thus, teachers prevented the online sharing of them. Finally, in order to avoid possible discomfort, in the educational intervention design, Makransky et al. (2020) tried to address the motion sickness, acting on technological level, thus reducing the high frame-rates.

3. Discussion

This literature review summarizes the current evidence on the use of X-Reality for science education at different school's levels (primary, secondary and high schools) and at higher education, showing an increase of students' learning achievement, attitude towards courses, student's learning motivation, and the science career aspiration. The search identified recent papers (9 published in 2020 and the other 5 in 2019-2018), demonstrating a growing interest in this educational approach. The results reported on the use of these digital technologies in science learning looks quite good, leading to the improvement of learning achievement, students' attitude, and motivation.

Nevertheless, there are some considerations raised from this analysis that need to be take into account to favour AR and VR integration into the science teaching practice. The first consideration regards the structure of the studies, in particular the design, the investigated outcomes, and the target group. Most of the articles have a quantitative approach with few articles that integrate qualitative data through semi-structured interviews (Weng et al., 2019, 2020; Chen, 2020; Beyoglu et al., 2020; Fidan et al., 2019) or open-ended questions (Weng et al., 2020) only aimed at investigating students' perceptions on learning activities. According to Arici et al. (2019), the reason of the choice of the quantitative approach is the need of an objective test, as well as time and cost-effectiveness, while the qualitative or mixed methods design are difficult to conduct and required time. However, the qualitative data could offer the advantage of improving the knowledge of learning processes, focusing on «the total picture rather than breaking it down into variables» (Ibanez et al., 2018 p. 13). Therefore, future studies should be planned to integrate the quantitative results with a more in-depth analysis of AR or VR educational interventions. Furthermore, only 1 study (Huang et al., 2019) compared the use of AR and VR, underlying that if AR can be more effective for the auditory information, VR is more effective for the visual one. It opens a new perspective, in which both AR and VR could be used as versatile tools to reach specific scientific learning objectives. Therefore, further studies are needed, focusing on AR and VR efficacy to foster scientific knowledge and abilities in different contexts, considering some variables as students age or scientific content.

From the literature it emerged that while students are pleased doing the activities with AR and VR, promoting positive attitude and enjoyment (Weng et al., 2020; Chen et al., 2020; Beyoglu et al., 2020, Fidan et al., 2019), no articles focused on teachers' perception or difficulties in designing and implementing these educational interventions.

As far as the outcomes, learning achievement, attitude (towards the subject and the innovative technologies) and motivation are concerned, they are the most investigated element. Only 1 study described the effects of educational intervention on science aspiration (Makransky et al., 2020), while no studies focused on the acquisition of the specific scientific laboratory's skills (as preparing solutions or creating a calibration curve). This is an important aspect, also underlined in the review by Reeves et al. (2020) since the laboratory experiences are of fundamental importance, especially in higher education, where they play a key role in scientific degrees. Usually, these activities require spaces and infrastructures to be carried out, but the opportunity to offer these experiences also in a virtual environment should be considered especially in this pandemic period. In this view, it is necessary to encourage comparisons between Virtual Labs with real field-work activities under the assumptions of equivalence (Reeves et al., 2020).

When considering the target group, most of the studies have been conducted on students from 4th to 8th grades (i.e., from 9 to 16 years old), followed by university and high school students. In fact, these students, in particular in the primary school, have some difficulties in understanding abstract concepts as the scientific constructs, requiring to make them more concrete through the visual approach, offered in this context by the AR and VR use (Sahin et al., 2020). Another consideration on the students' sample is about the influence of students' characteristics on learning outcomes. In fact, in the current analysis, some correlations to it have been identified: Cheng et al. (2020) demonstrated that in a VR environment students' intrinsic value and self-regulation influenced their perceived immersion, and students with lower levels of self-efficacy may have been more immersed in the VR, reaching positive learning attitudes. Weng et al. (2019) found significant differences between the learning outcomes of students with high- and low-level of spatial ability both in control and experimental group, concluding that 3D-animated AR and VR applications support mainly students with low spatial ability and decrease the gap between high and low spatial ability learners. Moreover, Makranski et al. (2020) showed that VR simulation increased the science aspiration in the female student that reached the same aspiration level of males. As the author explains, «this demonstrates the potential for VR simulations to contribute to balance out the gender difference in STEM fields» (Makransky et al., 2020, p 9). Accordingly, Madden et al. (2020) detected higher performance in males during VR experience, that has been correlated with the usual consumption of video games.

Looking at the inclusive perspective of this teaching approach, it must be underlined that these digital environments need to be accessible to all students: Fidan et al. (2019) recognized that the apps developed for AR science teaching could be difficult to use for learners with visual impairments (e.g., color blindness) or tactile disorders. On the other hand, through to its potential in zoom options, this app can facilitate learners with poor vision to see the objects. In this perspective, Arici et al. (2019) confirmed the need to focus on this sample group for future research. Thus, it is necessary to understand the technological characteristics to allow every student access, providing also some guidelines for X-Reality development for inclusive science teaching.

From a technological perspective, an important consideration involves the equipment needed to carry out the educational interventions, since AR and VR required some specific digital devices, such as tablets, smartphones or PC, as well as wearable ones for X-Reality environments. In this analysis some articles described research activities based on students' own phones (Weng et al., 2020; Beyoglu et al., 2020), others on offering devices to allow students working simultaneously (Fidan et al., 2019), and others on providing students with 2 VR headsets for simultaneously work. This could generate possible difficulties in class management as reported by Markowitz et al. (2018), underlying some problems for students not actively involved in the activities. Therefore, taking into account also that the use of HMDs is effective only to improve some abilities, as remembering or acquisition of spatial skills (Jensen et al., 2018), their use needs to be carefully evaluated. Moreover, it has also to be considered the limited effects that these digital technologies may have in certain conditions, as demonstrated by Chen (2020) who reported better results in natural science learning using digital games compared with AR. It implies a careful evaluation by teachers during the design of educational intervention of science topic, considering the more appropriate kind of technologies to be used according to the target and the scientific objectives to be achieved.

The reflection on proper technological choices is also connected to a third, a consideration related to students' and teachers' digital competence. Indeed, when taking into consideration the time and space devoted to the preparation of the students and the teachers for using X-Reality, most studies indicate that they receive digital training on these environments, before the start of the experimental phase, lasting from 10 minutes to 2 weeks to improve their digital competences and make them more confident with these tools. However, this is not enough to reach an appropriate and conscious use of these technologies by students and teachers, and there is a need to deeply explore the teacher's perspective, especially looking at how teachers can interact with students during these experiences. This is a key aspect, and it is also confirmed by Ibanez et al. (2018), underlining the need to improve design features to acquire basic skills on STEM disciplines and to understand how X-Reality learning activities can be integrated into blended instructional strategies. In fact, in the actual pandemic situation that forced the wider adoption of remote teaching, it has been clearly demonstrated the digital unpreparedness of teachers and students (Carretero et al., 2021), identifying in the lack of understanding on how to use digital technologies and in the lack of digital competence and equipment the main barriers that prevent teachers in using technologies in education (Carretero et al., 2021).

Finally, the drawbacks highlighted in this analysis can be divided into technological, cognitive and physiological issues. From technological point of view, the slow response of the system (Ibanez et al., 2018; Fidan et al., 2019) and the camera (Weng et al., 2019) and not intuitive interfaces (Ibanez et al., 2019) are the main problems, that must be considered since they may negatively influence students' learning. Usability (defined as «how easily the user is able to use the application» Salar et al., 2020, p. 7) is a variable correlated with the students' interest (Salar et al., 2020), and also shortcomings in visual presentation can influence the sense of presence in the immersive environments (Jensen et al., 2018).

The cognitive issue identified is related to the students' distraction, which may be due to the novelty of the approach (Ibanez et al., 2018), while the physiological discomfort included the dizzy effect of virtual trip (Cheng et al., 2020) or the arms and hand pain because of holding digital devices (Fidan et al., 2019). Thus, it is fundamental to reflect on these drawbacks in a perspective of digital well-being, balancing the opportunities offered by these new technologies for educational purposes with the downsides of their use (Melo et al., 2020).

Although some useful considerations can be drawn from this literature review, a limitation of this study is that the search has been performed only in Google Scholar, thus limiting the number of articles analysed.

Future research should focus on: I) teachers' perspectives, identifying their difficulties in designing and carrying out science learning activities through the integration of AR and VR and thus providing proper training; II) the influence of students' characteristics (e.g. gender, age, abilities) on the effectiveness of science learning activities using AR and VR to develop recommendations for the design of educational interventions; III) learning activities for acquiring specific scientific digital skills, in particular practical laboratory skills.

Conclusions

The results of this literature review on the use of AR and VR for science learning highlighted a great variety of studies' methodology, field of applications, technology use, target groups and outcomes. The growing interest in this topic is demonstrated by the higher number of recent articles (9 of 2020) and is due to the emerging benefits for learning achievements, attitudes and motivations. From a research point of view, further comparative studies are necessary to understand, for example, the type of technologies (AR and VR) to be used in different educational contexts or with different target groups, as well as the similarities between the virtual experience with the real one. Moreover, the research must focus more on learners' characteristics, and in particular on its impact on learning outcomes.

At the same time, there is a need to improve the digital competence of both students and teachers, in particular supporting them in designing educational intervention for the acquisition of scientific skills, overcoming the drawbacks and barriers that prevent the wide integration of digital technologies in science education.

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