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Virtual and augmented reality effects on K-12, higher and tertiary education students' twenty-first century skills

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Abstract
The purpose of this review article is to present state-of-the-art approaches and examples of virtual reality/augmented reality (VR/AR) systems, applications and experiences which improve student learning and the generalization of skills to the real world. Thus, we provide a brief, representative and non-exhaustive review of the current research studies, in order to examine the effects, as well as the impact of VR/AR technologies on K-12, higher and tertiary education students' twenty-first century skills and their overall learning. According to the literature, there are promising results indicating that VR/AR environments improve learning outcomes and present numerous advantages of investing time and financial resources in K-12, higher and tertiary educational settings. Technological tools such as VR/AR improve digital-age literacy, creative thinking, communication, collaboration and problem solving ability, which constitute the so-called twenty-first century skills, necessary to transform information rather than just receive it. VR/AR enhances traditional curricula in order to enable diverse learning needs of students. Research and development relative to VR/AR technology is focused on a whole ecosystem around smart phones, including applications and educational content, games and social networks, creating immersive three-dimensional spatial experiences addressing new ways of human–computer interaction. Raising the level of engagement, promoting self-learning, enabling multi-sensory learning, enhancing spatial ability, confidence and enjoyment, promoting student-centered technology, combination of virtual and real objects in a real setting and decreasing cognitive load are some of the pedagogical advantages discussed. Additionally, implications of a growing VR/AR industry investment in educational sector are provided. It can be concluded that despite the fact that there are various barriers and challenges in front of the adoption of virtual reality on educational practices, VR/AR applications provide an effective tool to enhance learning and memory, as they provide immersed multimodal environments enriched by multiple sensory features.

Keywords Virtual and augmented reality · K-12 · Higher education · Tertiary education · Twenty-first century skills

1 Introduction

1.1 Theoretical construct

Using VR/AR, students have first-person experiences while interacting with concepts, objects, experimenting with realistic objects and feeling immersed by using headsets, tactile gloves, and motion sensors (Martín-Gutiérrez et al. 2016). The drastic reduction in cost of technology and availability of high-speed Internet connection, as well as the rapid increase in the processing power of the computer, led to the deployment of desktop-based virtual reality technology in K-12, higher and tertiary education. In a comprehensive overview (Saltan and Arslan 2017), state of the art for the use of AR applications in formal education is illustrated and the educational outcomes arising are found to be attention,

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engagement, interest, motivation, satisfaction, knowledge comprehension, academic achievement, knowledge retention, enjoyment and autonomy. The basic idea of AR is to mix reality with virtual reality namely more information data such as graphics, audio, senses, touch, smell and taste which are superimposed over a real-world environment to make the user to interact with the virtual images (Yu et al. 2009). As it is described below K-12, higher and tertiary education students' twenty-first century skills that VR/AR technologies improve are in line with the revised Bloom's Taxonomy (2001) educational objectives which students are expected to learn as a result of instruction. The cognitive and knowledge processes demonstrate a two-dimensional framework complexity from lower order thinking skills (LOTS)—remember, understand, and apply—to higher order thinking skills (HOTS)—analyze, evaluate and create. Specifically, the cognitive process dimension represents six categories of increasing cognitive complexity (remember, understand, apply, analyze, evaluate and create) displaying a wide range of skills, and the knowledge dimension (factual, conceptual, procedural and metacognitive) representing a wide range of types and subtypes which integrate the skills that VR/AR technology improves throughout the curriculum in education levels (Anderson et al. 2001; Bacca et al. 2014; Radu 2012). The literature presents numerous advantages of using virtual reality-based instruction as effective means for the educational institutions planning to invest time and financial resources in order to enhance learning outcomes and see the learning and cognitive benefits in their students (Lee et al. 2010; Merchant et al. 2014). Additionally, VR features were found to be significantly related to usability, presence, motivation, control, active learning and reflective thinking depending on the students' spatial abilities and types of learning styles (Lee et al. 2010). Virtual technology systems enable the incorporation of 3D digital worlds in education to introduce abstract, difficult to assimilate, dangerous, and/or conventionally inaccessible information and experience, and strengthen the development of creativity and collaboration in the learning process (Akçayır and Akçayır 2017; Sanabria and Arámburo-Lizárraga 2016; Yilmaz and Goktas 2017). Competency in twenty-first century skills gives people the ability to keep learning, negotiate constant change and reinvent themselves for new situations. twenty-first century skills in education include the concept of creativity, collaboration, communication, social skills, critical thinking, problem solving and digital-age literacy (Bellanca and Brandt 2010; National Research Council 2013; Sanabria and Arámburo-Lizárraga 2016; Radu 2012).

1.2 Definitions

Martín-Gutiérrez et al. (2016) states that virtual reality (VR) refers to a whole simulated reality which requires hardware and software powerful enough to create an immersive 3D spatial experience. Orlosky et al. (2017) indicate that VR is a technology that immerses a user into a computer-generated virtual world by replacing the real world around the user with a virtual one. Accordingly, AR is a technology that overlays computer-generated information onto the real world (Yu et al. 2009; Wu et al. 2013).

Next generation virtual and augmented reality applications will benefit the most from the 5G network features that will allow up to 10 Gbps of mobile data transmission per device and will add another modality of realism to virtual and augmented reality applications without wires or tethering (Orlosky et al. 2017). Virtual environments (VEs) or immersive virtual environments (IVEs) are 3D-computerized representations of "real world" which allow the user the freedom to interact with objects and people and can be realistic enough to simulate and assess social situations (Wallace et al. 2010).

National Research Council (NRC) organized a committee on defining a set of key skills referenced among others by the label twenty-first century skills drawing on a large research base in cognitive, developmental, educational, organizational, and social psychology and economics. The report proposed a preliminary taxonomy with clusters of competencies identifying three domains of competence: cognitive, interpersonal, and intrapersonal. The cognitive domain involves thinking, reasoning, problem solving and memory, and the interpersonal domain includes competencies that are used both to express information to others and to interpret others' messages and the intrapersonal domain involves emotions feelings and self-regulation. Among the terms used for the twenty-first century skills in the cognitive domain are critical thinking, problem solving, creativity and executive function (National Research Council 2013).

Executive function includes the concept of cognitive flexibility, inhibition and working memory which are related to math and literacy achievement in elementary-aged children (Vitiello and Greenfield 2017). Moreover, there are two distinct subgroups: metacognitive and emotional/motivational executive functions. The first refers to response inhibition conflict monitoring and switching, temporality of behavior, self-consciousness, working memory, abstraction and problem solving, and the latter entails the coordination of cognition and motivation as well as the ability to control emotions and behavior (Ardila 2016; Drigas and Karyotaki 2017). Executive function and metacognition are higher-order cognitive processes which are highly relevant to daily functioning in various domains including academic achievement and play a key role in self-regulated learning (Roebers 2017).

Twenty-first century skills are vital for improving learning and innovation skills, life and career skills, information and media skills, as well as core subjects and twenty-first century themes that are expected and highly valued in school, work and community settings. Language used to describe twenty-first century skills is not rigid. Adaptability and resilience, critical thinking and systems thinking, flexibility and adaptability, social and cross-cultural skills are examples of the wide range of the same concept. Student outcomes in twenty-first century skills require every aspect of the educational system to be aligned toward this goal (Bellanca and Brandt 2010; Ledward and Hirata 2011; Trilling and Fadel 2009). Using technological tools such as interactive devices and AR that combine real and digital worlds makes it easier for users to autonomously produce flexible learning to enrich learning experiences that foster the development of twenty-first century skills in educational contexts (Martín-Gutiérrez et al. 2015; Sanabria and Arámburo-Lizárraga 2016).

1.3 Methodology

In this paper we provide a brief, representative and non-exhaustive review of the current research studies arguing the extent to which virtual/augmented reality plays in the development of the K-12, higher and tertiary education students' twenty-first century competencies, including articles that deal with concepts involving students of both mainstream and special education and training. The manuscript selection process includes a defined set of articles from important journals within the field, according to the criteria illustrated in Table 1.

As Akçayır and Akçayır (2017) argue, AR has only recently become very popular in educational settings. Thus, drawing from our experience in interacting with the empirical evidence in the literature arising from each participant author's exclusive research or work domain, we explore a sample of representative studies affecting K-12, higher and tertiary education students that highlight the theoretical and practical aspects of the use of VR/AR technology. On the other hand, these studies propose good practices in the education of the dominant skills and executive function that a mainstream or special education student needs to become a citizen in the twenty-first century. The phrase "twenty-first century Skills" provides a holistic view of the learning environment required to enable students and teachers to engage in knowledge and skill development encompassing several inter-related skill sets: life and career skills; learning and innovation skills; information, media, and technology skills; and core subject mastery and familiarity with interdisciplinary themes (Ledward and Hirata 2011). Although there is a considerable overlap among proposed lists of "twenty-first century skills" as referred in the NRC 2013 report, in which executive function is only one of them, it is critical to involve this skill in the research process as a core element of students' self-regulation for both their learning and school readiness (Drigas and Karyotaki 2017; Vitiello and Greenfield 2017). Big attention is paid to special education students with mental, attention, developmental and visuospatial disabilities as evidence of the high efficiency level that VR/AR technology usage has on their impairments and deficiencies compared with traditional educational methods. K-12, higher and tertiary education students are considered as a whole, whose twenty-first century skills are explored representatively based on a 6-level layer of skills which are as follows: (1) retention and memory, (2) motivation and attention, (3) visuospatial skills, (4) learning and critical thinking, (5) collaboration, communication and social skills, and (6) immersion, creativity and emotional skills.

1.4 Background knowledge

There is an ever-increasing demand for technology-based interactive devices to support learning through technologies such as augmented reality (AR) and virtual reality (VR) systems that combine real and digital worlds (Sanabria and Arámburo-Lizárraga 2016). A new landscape of business exploitation is being created by companies such as Google, Facebook and others regarding innovative services for the agenda of human–computer interaction (Lytras et al. 2016). A wide range of real-life firms see virtual worlds as an additional marketing environment in terms of revenues generated and transacted placing their brand and (digital) equivalents of their real-life products (OECD 2011).

All AR/VR manufacturers want to win the race for this global business that invested \$2.3 billion into AR/VR startups last year, which is a 300% investment growth in 12 months in an early stage market and is expected to obtain \$120 billion profits in 2020 mainly by creating

Table 1 Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
(a) Must involve VR and/or AR as a primary component	(a) Articles before 1998
(b) The article must be about K-12, higher and/or tertiary education students	(b) Articles that refer to medical, military, tourism or industrial settings and corresponding VR/AR applications
(c) Must refer to VR and/or AR added value on students executive function or twenty-first century skills as illustrated in Sect. 1.1	

virtual contents and manufacturing headsets to visualize these contents (Digi-Capital 2016, 2017; Martín-Gutiérrez et al. 2016).

Categories included are: AR Headset Mounted Devices (HMD) (hardware), AR/VR Solutions/Services, VR Video, VR HMD (hardware), VR/AR Peripherals (hardware), VR/AR Games, VR/AR Applications (non-games), VR/AR Advertising/Marketing, VR/AR Tech (hardware and software) and VR/AR Distribution.

The attitudes of students toward virtual reality as a tool in the educational procedure and toward virtual learning environments in specific disciplines indicate that VR is highly promising as a learning and teaching tool expressing positive feelings of enthusiasm and impressiveness declaring immersion experiences (Mikropoulos et al. 1998).

VR supports the creation of highly interactive 3D environments and may be used as learning or educational environments at all educational levels and in all disciplines from sciences to humanities involving multi-sensory channels for user interaction through natural manipulation in real time (Mikropoulos and Bellou 2006).

Even if immersion appears as a result of the involvement of more than one perceptual channel such as visual, auditory, haptic and olfactory interactions, visual representations predominate (Mikropoulos and Natsis 2011). Christou (2010) argues that this experiential nature of VR together with its other feature, interactivity, provides a valuable aid to conventional learning paradigms and tries to explain this effectiveness in terms of the advantages afforded by active learning from experiences. This usefulness is derived from the fact that VR provides the opportunity to visualize the macroscopic world as well as the microscopic world at a human scale compatible with a constructivist view of education which is physically impossible to set up in the classroom. Immersive VR, if properly designed, may support the type of multi-sensory learning environments that enable students to rely on their biologically innate ability to make sense of physical space and perceptual phenomena (Salzman et al. 1999).

The multimodal possibilities of AR applications in education are found to be effective for a better learning performance, learning motivation, student engagement and positive attitudes and address the special necessities of diverse population supporting therapy processes for people with sensory and physical impairments (Bacca et al. 2014; Radu 2012).

Below, we exhibit a representative but not exhaustive series of studies examining VR/AR effects on students' retention and memory, motivation and attention, visuospatial skills, learning and critical thinking, collaboration, communication and social skills, immersion, creativity and emotional skills. The researches listed indicate the rapidly emerging potential for VR/AR industry to invest in education market.

2 VR/AR effects on students' retention and memory

It is proposed by Zarzo (2015) that the implementation of the art of memory in educational experiences within a virtual learning environment (VLE) following the classical rules of mnemonic art favorably contributes to the development of the students' analytical and synthetic abilities. Students recorded a significant improvement in their critical capacity in a series of educational activities elaborated with *Mind-mapping* software and implemented using a *Moodle* platform. The activities were designed in a VLE that allowed senior high school students studying Philosophy to organize knowledge in a reticular, multidisciplinary and comparative way and enabled them to work collaboratively in the teaching/learning process with a sense of individual responsibility (Zarzo 2015). It is also demonstrated that using a first-person gaming platform through a virtual environment (VE) protocol memory recall substantially improved relative to a control group. This VE protocol may also be useful for age-related memory impairments and for those who have deficits due to neurological damage (Legge et al. 2012). Additionally, VR applications may promote an increase in working memory and attention levels of individuals with traumatic brain injury (TBI) improving the quality of their life (Gamito et al. 2011). Sárkány et al. (2016) presented a VR human–computer interaction scenario to stimulate the memory and thinking process of dementia patients, while they perform everyday activities in VR. hand gesture tracking, as well as an Oculus Rift integrated gaze and eye tracking system were employed to recognize the gaze patterns and detect hand poses in real time. Physical interactions through very natural control actions such as movement of the head to look around and hand movements for the manipulation of the 3D serious game employing artificial general intelligence were found to maintain and improve mental health. Cognitive disorders at their very earliest stage could be detected exploiting such methods to individuals who are still healthy and have not exhibited signs of cognitive impairment as they can be motivated to self-monitor and train their cognitive function (Zygouris et al. 2017).

3 VR/AR effects on students' motivation and attention

In a study conducted by Cascales-Martínez et al. (2016) an increased motivation was found in students with learning disabilities, learning disorders not otherwise specified and attention deficit hyperactivity disorder working with a tabletop system with the ability to support augmented reality applications. Students could visualize and manipulate mathematical problems in a virtual shopping simulation game using their desks as interactive surfaces where the system could recognize multi-touch (multiple fingers and hands) interaction. Results provided several reasons why the tabletop instructional effectiveness is higher than that using traditional construction tools showing that students with special educational needs have increased their math knowledge and participated in the activities enthusiastically attending the lessons on time.

Lorenzo et al. (2013) presented an immersive virtual reality (IVR) system as a support tool in the educational intervention of Asperger syndrome students in accordance with their social competencies and their executive function. The goal of the IVR is to give the user the impression that he/she has "stepped inside" the synthetic world and has the possibility to interact with it manipulating the existing objects in the virtual world. The IVR system provides the immersive effect through a projection on an L-shaped screen, 3D active viewing, high quality audio and a precise positioning system complemented by a Kinect sensor that allows capturing the student's movement within the immersive environment. The students can interact with virtual persons that appear in the virtual environment and listen to the researcher who can use audio to talk with the children to guide them. High scores obtained in "attention control," "voice control" and "motor coordination control" indicated a significant improvement in the behavior of the students. The results of the study show that students with Asperger syndrome can improve the acquisition of executive function allowing them to interact with full autonomy and motivation.

Wallace et al. (2010) state that the use of IVR can improve the learning of students with autism spectrum disorders (ASD) because of the possibility to repeatedly reproduce real environments and situations presenting either a residential street or school playground or school corridor scene. The level of presence that the students with ASD show in the IVR environment they designed implies that such environments can be safe places to motivate and engage children with ASD. VR can provide an effective platform of authenticity and levels of realism for learning and assessment of individuals with ASD whose social interactions and communications can be controlled, explored, examined and supported (Parsons 2016).

VR allows learners to interact with virtual objects at their own pace and learn through a constructivist approach, encouraging active participation rather than passivity. Thus, VR has the potential to lead learners to new discoveries, to motivate and excite them modeling the real world and requiring interaction as being part of the environment. The use of a model for determining when to use VR in education and training can help the educator or trainer decide when to use it so it can be tailored to learners' characteristics and needs and easily grab their attention (Pantelidis 2010). Virtual worlds become an excellent opportunity for educators to implement learner-centered pedagogies where students take an active role to perform simulations and learn by doing activities which otherwise would be impossible to carry out due to its expense or location. The simulation environments improve the involvement rate and stimulate active participation providing support to students with specific needs (González et al. 2013).

4 VR/AR effects on students' visuospatial skills

In a virtual world, avatars can not only share text, video and audio files, but also voice and visual expressions (OECD 2011). 3D visualization or projections of visual information have brought forward more than 150 universities and educational institutions to adopt this kind of environments (González et al. 2013).

In a study by Novotný et al. (2013) a multi-touch augmented reality system (MARS) using two display units for showing two contexts of the same object(s) proved to be an effective mixture that attracts viewers to educational or cultural content. The researchers created an application for history education which combined historical maps as the primary context with 3D presentation of historical buildings in the secondary context where students were able to improve the understanding of spatiotemporal relations and understand the topic. The results showed that for 85% of the students, this kind of demonstration helped them remember over 40% more information about spatial and temporal relationships compared to traditional methods. Similar to this system is a Visual Interaction Tool for Archeology that combines speech, touch, and 3D hand gestures to interact multimodally with the environment merging the real world with superimposed virtual images. Additionally, a glove-based gesture recognizer supports three distinct gestures (point, grab, and thumbs-up) combining the advantages of both real and virtual environments (Benko et al. 2004).

Virtual laboratories and virtual worlds can overcome difficulties in the fields of science, technology and engineering (STE) supporting the introduction of new emerging technologies such as computer graphics, augmented reality, virtual worlds and computational dynamics in all aspects of education. Although more advanced learners will still need hands-on experience with real equipment, immersive education applied by virtual laboratory systems and simulators is the desired initial step in STE education either formal-institutional or informal-massive and professional training in companies as well. Some of the advantages of a virtual laboratory over the physical one include: flexibility involving different components that can be easily created allowing damage and multiple access by students using the same virtual equipment at the same time. Furthermore, another way to enhance students' fine visual-spatial skills is the possibility to modify parameters that often cannot be changed in a real system and learn from mistakes (Potkonjak et al. 2016). Virtual reality, aided by the 5G network, promises to be able to provide an even more effective way of teaching ensuring access to a new generation of haptic/tactile educational interfaces that improve the efficiency of teaching infrastructure (Orlosky et al. 2017).

5 VR/AR effects on students' learning and critical thinking

Lots of educational institutions and universities such as Drexel University, Emory University, New York University, Princeton University, Stanford University, and University of Florida have already set up their own virtual learning platform trying to utilize this educational medium as a means for better student engagement in the learning activities. Furthermore, students can participate in learning activities from anywhere; navigation in the virtual learning space is a matter of a digital manipulation of the virtual world without any physical constraints overcoming the barriers of distance, time and locations, instructors and students can meet and interact more easily, the "game" nature of virtual worlds may have a positive impact on students' constructivist and experiential learning. The researchers argued that 3D virtual environments can facilitate constructivist learning by providing learner-centered conditions that would make learning more flexible and give students a unique learning experience. Also, students in the experimental group comparing with those in the control group acquired higher perceived learning outcome achievement (Chau et al. 2013). Besides, students consider the setting is nice, comfortable, spacious and suitable for learning allowing them to abstract from their real environments due to the high sensation of immersion on the scenario (González et al. 2013). Students indicate that by designing AR, they are centered in the learning experience by virtue of being placed in the role of authentic designers and that the challenge made them "want to go in depth" (Bower et al. 2014).

AR is one technology that dramatically shifts the location and timing of education and training though adopting it in classroom-based learning within subjects like chemistry, mathematics, biology, physics, astronomy, and other K-12, higher and tertiary education contents into augmented books is still challenging (Radu 2012). There is much optimism of AR in education and training for the future as long as it combines real world with augmented information in interactively seamless ways. AR can make educational environments more productive, pleasurable and interactive and provide each learner with one's unique discovery path. In addition, AR could probably be focused on simplicity and ease of providing education and making training experiences much more straightforward, succinct to approach and successfully utilized when students take control of their own learning (Lee 2012).

6 VR/AR effects on students' collaboration, communication and social skills

As for the use of 3D immersive virtual worlds in K-12 and higher education settings Hew and Cheung (2010) found that virtual worlds such as "Second Life" may be utilized for communication spaces, simulation of space and experiential spaces where the user has the ability to "act" on the world communicating with one another using either the chat tool or direct visual interaction.

The use of virtual worlds allows users to virtually experience information by changing the communication environment from a flat, text-based one-dimensional interface to a rich, multicolor, immersive 3D environment that has many potential uses in teaching and learning education settings (Chow et al. 2007). With regard to users' satisfaction, students liked using the visual worlds because of the ability to fly and move around freely in a 3D space, to socialize and meet new people and to experience simulated field trips. Also, it is suggested that the use of personal avatars among participants while "acting" on the virtual world could help foster their interaction as it socially connects people from different parts of the world "who you would probably never meet in real life." The technology of 3D virtual worlds is being expanded and improved in a way that allows students who are scattered geographically to take advantage of a class that bridges this gap by giving students the feeling of being present with other classmates and with the instructor. Overall, Second Life and other virtual environments have the ability to create a shared experience for the students and the instructor to work together collaboratively and demonstrate instruction, respectively, participating in the emerging social network by creating a group or joining an existing one (Chow et al. 2007; De Lucia et al. 2009; Hew and Cheung 2010).

Michailidou and Economides (2002) constructed a virtual world named ELearn for teaching some of the basic aspects of electronic commerce using an environment that integrates collaboration and interaction. The virtual school has the capability of synchronous chat among the users including online lessons of electronic commerce integrating six spaces: the reception room, the selection room, the lessons room, the library, the lecture room and the electronic store.

Collaborative virtual environments compared to traditional ways of training are proved to be cost effective; thus, commercial interest in developing virtual environments appears to grow significantly (Martín-Gutiérrez et al. 2015).

Additionally, there are psychological themes such as personality, attitudes toward technology, self-image and cognitive ability that affect user's experience of virtual worlds. As long as virtual worlds bring together people who are physically located in venues from around the world, they involve the complex sociology defined by the physical and jurisdictional structures that exist outside of the virtual realm. These new forms of communication will engender vastly different user experiences and uses for virtual world technologies. In general, they are immersive "game-like" environments where participants use an "in-world" representation to engage in a variety of activities on issues related to the user interface (haptic, audio and visual) that provide users role-playing opportunities. Virtual worlds like World of Warcraft, Second Life and similar environments have the potential to dramatically change how people interact with existing corporate and consumer-focused applications. The solution to the difficult problems of tactile feedback and "real-world" simulation could lead us to an exciting and new frontier for e-commerce (Mennecke et al. 2008).

Schmidt et al. (2012) presented a case study of developing and implementing methods to capture, code and comprehend reciprocal social interactions in a three-dimensional virtual learning environment (3D VLE) to help youth with autism spectrum disorders (ASD) develop social competencies. Results illustrated detailed descriptions of learning and social interaction behavior demonstrating how learning takes place and progresses in a 3D VLE and improves the learning experience in the online social context. The dominant mode of interaction was verbalization with a mean percentage of 51.48% across participants. Their paper described an approach to collecting and representing discrete behaviors of individuals within activity and learning contexts accounting for characteristics and affordances unique to the 3D VLE addressing the complexity of learning when mediated through the virtual environment and using avatars as representative of participants.

In support of the aforementioned research, Parsons (2015) presented the design of a novel collaborative virtual reality environment (CVE) for supporting communicative perspective-taking skills for high-functioning children with ASD suggesting that this CVE could form the basis for a useful technology-based educational intervention. The study suggests that children with ASD were supported by the structuring of the CVE-based tasks, and teacher facilitation, to collaborate and communicate in a reciprocal way illustrating a model approach where the development of the CVE emphasizes the importance of learners working together on tasks, the selected technology could only be used by more than one person interacting with them concurrently and teachers' views formed a strong part of learner-centered design activities. The CVE game was designed as a two-player interaction in which children had to verbally communicate and collaborate with, and understand the perspective of the other child in order to resolve the problem and complete the game as independently as possible. Facilitators were encouraged to provide a contingent, responsive and supportive role as needed. Results were encouraging showing that the children with ASD made sustained endeavors to communicate with their partners despite their well-documented difficulties in social reciprocity (White et al. 2007).

Virtual reality can create a realistic ambience and provide a platform where users meet through an avatar and communicate with other people or find some kind of entertainment in the so-called virtual environments (VE) which with the specific purpose of enabling, teaching and learning creates the virtual learning environment (VLE). Advanced VLE based on the dynamics of present real-world objects lie in the area of alternative input/output devices (e.g., haptic, motion sensing feedback and VR headsets) (Potkonjak et al. 2016).

7 VR/AR effects on students' immersion, creativity and emotional skills

VR/AR has been applied in education as creative tools for enhancing traditional curricula and learning techniques to change the role of the learner and become a transformer of knowledge rather than just a receiver of information (Sanabria and Arámburo-Lizárraga 2016). 3D virtual learning environments (VLE) are open learning environments in which users design and create their own objects (Merchant et al. 2014). The virtual tools in this type of platform simulate social reactions where creativity, observation, spatial orientation, conflict resolution, social empathy, competitiveness and respect are developed, while the player faces problems that must be solved by means of constant decision making (López and Cáceres 2010). Additionally, research revealed that the effective and successful use of VLE is influenced by the learning readiness, attitude, and learning style of the student which in turn are used to personalize the AR/VR environments (Jena 2016; Kurilovas 2016). With technology acceptance, we will enjoy a stream of creations, services and products like art and learning enhanced by virtual galleries and learning kiosks, combining entertainment, learning and work into one experience. In VR world, Second Life (SL) "creation" constitutes the greatest invention and technological achievement that gives users the capability to develop their own "things." In fact, the entire contents of SL are created by users. Some of the facets of creation in virtual worlds are avatars, objects and land where the user is allowed to advance from simple arranging functional options to complex and flexible making of additional functions (Sivan 2008).

Lorenzo et al. (2016) created an immersive virtual reality system (IVRS) to improve social and emotional deficits shown by children with autism spectrum disorder (ASD). Also, the researchers used the IVRS to train and intervene in the development of emotional competencies and transfer of the learned skills into real contexts. The system made up of elements, such as virtual environments or immersive scenarios, was used to provide the children with visual and interactive learning to improve social and emotional competencies. Additionally, a robot with an eye-in-hand camera system was employed and software components for the researcher to interact with the child. As the social situation is introduced to the children, the evaluator constantly interacts with them to make them familiar with the virtual environment. The results of this study showed that the immersive environments offer a high degree of interactivity with the user and consequently more appropriate emotional behaviors in the immersive environment in comparison with the use of desktop VR applications. Furthermore, the emotional behaviors in the real school environment have improved indicating that it is possible to transfer and generalize the skills trained in the IVRS to real situations.

Huang et al. (2016) developed an innovative AR-based learning model to allow students to become immersed in environmental exploration and interaction with AR-enhanced ecological information in a botanical garden setting. The study showed that the AR exploration mode provided by the proposed system increased students' willingness not only to learn more about the environment, but also to develop a more positive emotional attachment to it. The AR system enhanced students' sense of fun in exploratory learning aroused their curiosity and empowered them to explore and study on their own, giving them a greater sense of competency, thereby enhancing learning experience and positive emotions. As one student noted: "I felt bored when I visited this place before; it is fun this time with the tablet," indicating that learners derive more pleasure integrating the virtual–actual AR interaction in learning.

In a study by Chen et al. (2016), an augmented reality-based video-modeling (VM) storybook (ARVMS) was used to help children with ASD better understand the facial expressions and emotions of the storybook characters. ARVMS strengthened and attracted the attention of children with ASD to nonverbal social cues as it extended the social features of the story and restricted attention to the most important parts of the video. The content of the video was based primarily on situations and social communication that children might encounter in their daily life. The research intended to train and test students' ability to identify the six basic emotions which are difficult for children with ASD to grasp and understand: anger, fear, disgust, happiness, sadness and surprise. With the help of advanced AR technology, computer-generated sensory inputs such as sound, video, and graphics were created using the Vuforia platform and the Unity Extension Application Program Interface (API). The AR was used to attract the children's attention, and the VM encouraged them to mimic the nonverbal content of the social interaction and feel the reflected emotions. As parents mentioned in the questionnaire feedback reports about their children, the ARVMS helped them to show good improvement in social and emotional awareness. The researchers conclude that using the ARVMS helped children with ASD in social skills to judge different nonverbal social signals and switch their attention from inanimate objects to the key elements of the social stories.

It is concluded that immersive virtual reality learning experiences using a head-mounted display technology allow students to gain a greater understanding of abstract concepts creating visual metaphors, manipulate and scale virtual objects for clearer understandings, and visit places that distance, time or safety concerns would normally prohibit. Immersive VLEs can provide beneficial educational experiences through the sense of presence in and ability to interact, the ability to travel through time, the provision of rich visual metaphors, and the autonomy in the learn-by-doing constructivist form of activities (Jackson and Fagan 2000).

8 Gaps, challenges, limitations and criticisms in the reviewed articles

In this section, most frequently appearing challenges of the literature review papers are mentioned. Problems that appeared during researches refer to the dizziness some students expressed wearing the VR headset and their refusal to wear it requiring a period of familiarization. The ongoing training of the participant teachers is another important aspect in order to involve them in the process of the VE study (Lorenzo et al. 2013). As it is revealed, a notable gap exists for AR studies focused on students with special needs (Akçayır and Akçayır 2017; Yusof et al. 2014). The challenges imposed by AR use within educational settings involve the difficulty for students when using the technology, significantly longer mean training times compared to non-AR-using group, low sensitivity in triggering recognition, students' frustration due to GPS errors, learner differences, unsuitability for large group teaching, camera or Internet technical problems, cognitive overload due to the complexity of the tasks, higher attentional demands, teachers' inadequate ability to use the technology, and other minor application-related and technical problems (Akçayır and Akçayır 2017; Chen 2008; Chiang et al.2014a, b, Dunleavy et al. 2009; Freitas and Campos 2008; Kerawalla et al.

2006; Ke and Hsu 2015; Muñoz-Cristóbal et al. 2015; Wu et al. 2013). Educational technology reviews report limitations in the evidence base as a result of small sample sizes and research design weaknesses and deal with possible reluctance to use and integrate the new technology into a course or curriculum. A reason of primary importance not to use VR in education is if interaction with real humans, either teachers or students, is necessary (Pantelidis 2010; Parsons 2016). Limitations which may affect the generalizability of the findings might be the limited relevance of the learning content to a wide range of students and the limited experimental duration due to time and logistical restrictions (Huang et al. 2016). Studies that are limited in their duration present that students and teachers are more likely to use and enjoy virtual worlds because the technology is new to them compared with participants who used them for a longer period of time, and so results should be interpreted with caution. Purposive sampling was the major limitation of a study where selection biases might have been operated among the study participants (Chen et al. 2016). Additionally, many of the studies that obtained positive results did not utilize a control group which after a deeper analysis was attributed more to the scenario (instructional strategy) rather than to the virtual world (Hew and Cheung 2010; Parsons 2015). Bandwidth is also a significant limitation for applications that need the transmission of gigabytes of dense model to create a 3D reconstruction or telepresence. Perception and performance can be affected by many types of delays if the feedback is engaged too long after the visual stimulus has occurred (latency) (Orlosky et al. 2017). One of the criticisms regarding the use of the VR/AR technology for learning is that it might be costly for some mainstream institutions to be of much educational use beyond niche academic research (Novotný et al. 2013; Wallace et al. 2010). Other negative side effects that influence the user's subjective experience of a VR/AR environment refer to a condition known as simulator sickness similar to motion sickness, headache, eye strain, pallor, sweating, dryness of mouth, fullness of stomach, disorientation, vertigo, ataxia, nausea and vomiting which can drastically diminish usability of a system if not taken into account. Possible reasons of such negative side effects may be accommodation problems, low frame rate, lag or bad fitting HMDs helmets which can be caused due to imperfections in the technology especially with visual displays (Kaufmann and Dünser 2007; LaViola 2000).

9 Results and discussion

Bold innovations in technology such as VR/AR will gain increasing importance in the next years due to the exploitations of virtual learning infrastructures that promote flexible, open, and collaborative learning beyond time, personality, and place constraints within virtual classrooms of educational institutions all over the world (Lytras et al. 2015). Besides, virtual worlds provide realistic and interactive role-playing simulations where students gather and interact in real time, experiencing a shared sensation of being together in the virtual space in which learning is an activity where location is less important as it does not rely on physical space (González et al. 2013). Furthermore, virtual worlds found to have uniquely positive aspects for educational purposes being able to create virtual learning environments and enable a greater variety of classes to be taught socially connecting people and organizations from different parts of the country and world "who you would probably never meet in real life" (Chow et al. 2007).

Virtual reality fosters users' ability to "feel" the reality, change and modify it and use his/hers visual, auditory, tactile, smell and taste senses to solve a problem in line with his/her immersion, interaction and imagination providing the sensation of "being there" with others (OECD 2011; Sivan 2008). Results demonstrate that virtual environments improve substantially memory recall of lists with categorically similar items where the teacher encourages the student to reflectively construct their own internal space (Legge et al. 2012; Zarzo 2015). Additionally, students working with augmented reality environments increased assimilation of knowledge as they increased their collaboration between them (Cascales-Martínez et al. 2016).

Although there are a number of barriers and challenges to the adoption of virtual reality worlds, related to intellectual property rights and digital content policy frameworks, there is evidence of the potential for using them for collaboration, creativity and learning in the private as well as in public education and training sector including areas such as entertainment, tele-working, e-commerce, research and others (OECD 2011).

Augmented reality can be used by educators to develop students' higher order thinking skills encouraging learning by design that requires skills like analysis, evaluation and creation contributing to the ultimate growth of students (Bower et al. 2014). Efficiency and effectiveness of AR in education and training has been proved in almost all domains of the K-12 and higher education curriculum such as mathematics, geometry, physics, science physics, biology, chemistry, astronomy, history, geography engineering robotics or non-robotics and other academic subjects providing attractive, stimulating and exciting experiences for students (Furió et al. 2013; Lee 2012; Muschio et al. 2015; Potkonjak et al. 2016; Radu 2012). With its simplicity, portability and wide application, AR has enabled learners to produce flexible learning and learning techniques that follow the design principles of various theories such as Gardner's theory of multiple intelligences (MI) (Gardner 1983) which disrupt traditional systematic patterns for generating knowledge and skills (Furió et al. 2013; Sanabria and Arámburo-Lizárraga

Table 2 Main results of the review of VR/AR impact on twenty-first century skills

Promote flexible, open and collaborative learning
Provide realistic and interactive role-playing simulations
Enable a greater variety of classes to be taught socially connecting people and organizations
Fosters users' ability to "feel" the reality, change and modify it
Improve substantially memory recall of lists with categorically similar items
Students increased assimilation of knowledge as they increased their collaboration between them
Potential for using them for areas such as entertainment, tele-working, e-commerce and research
Develop students' higher order thinking skills encouraging learning by design
Efficiency has been proved in almost all domains of the K-12 and higher education curriculum
Virtual worlds foster students' social skills using avatars

2016). Well-designed VEs can be safe places to assess and educate children developing animated sequences of social situations suited to their preferences being applied to all aspects of education, including formal-institutional education, informal-massive education and professional training in companies (Dalgarno and Lee 2010; Kye and Kim 2008; Potkonjak et al. 2016; Sollervall 2012; Wallace et al. 2010). Studies suggest that students like using virtual worlds because they enjoy meeting new people and experience simulated interactions that foster their social skills using avatars (Hew and Cheung 2010).

In Table 2, main results of the review of twenty-first century skills in their connection to VR/AR are presented.

This review describes an ongoing discourse about how VR/AR technology impacts on pedagogy of current educational systems across different cultural context, contents or learning needs and will likely revolutionize the way we think about education in the traditional classroom that gradually fades into history (Orlosky et al. 2017). From the researchers, designers, developers and implementers scope, it is suggested that further studies are required with a larger sample size on different age groups in different educational aspects to investigate the effectiveness and advantages of using virtual/augmented environments to discover its potential as an educational resource and facilitate constructivist teaching and learning (Chau et al. 2013; Schmidt et al. 2012; Wu et al. 2013). Orlosky et al. (2017) argue that we still largely have not taken advantage of the capabilities of all that AR and VR have to offer in the domain of immersive and hyper-realistic experiences through exciting new human–machine interfaces.

10 Conclusion

In this article, we exhibited a brief, representative and non-exhaustive literature review of virtual and augmented reality effects on K-12, higher and tertiary education students' twenty-first century skills. Research community shows an increasing interest to use VR/AR technologies for students' cognitive or metacognitive screening and training that improves higher order thinking required for performing complex or non-routine tasks. In this review, studies published mostly in ScienceDirect (Elsevier), SpringerLink and Scopus database journals were analyzed. The results showed that although there are a number of barriers and challenges to the adoption of virtual reality worlds within educational settings, VR/AR applications provide an effective tool to enhance learning and memory as they provide immersed multimodal environments enriched by multiple sensory features. Users interact multimodally with both virtual and augmented environments combining their haptic audio-visual skills that meet their needs. It is also illustrated that there is strong evidence for significant improvement on students' learning, social and creative skills. Additionally, implications of a growing commercial interest for the envisioned trend which is used in various aspects, such as effective tele-education, were provided. Systematic and exhaustive research on the direction of the literature discourse analysis we dealt with in this review could provide further evidence in the field. Future researchers may wish to examine systematically emerging research points of this study regarding both positive and negative VR/AR technology's learning effects. Specifically, considering the potential of VR/AR for increased content understanding, long-term memory retention, increased student motivation, improved collaboration as well as to prevent negative consequences such as attention tunneling, usability difficulties, ineffective classroom integration and learner differences (Radu 2012).

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