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Article *in* Asia Pacific Education Review · February 2017

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Asia Pacific Educ. Rev. (2017) 18:81–100
DOI 10.1007/s12564-016-9467-0

3D virtual learning environments in education: a meta-review

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Received: 4 June 2016 / Revised: 16 November 2016 / Accepted: 22 December 2016 / Published online: 13 February 2017

Abstract The aim of this study is to investigate recent empirical research studies about 3D virtual learning environments. A total of 167 empirical studies that involve the use of 3D virtual worlds in education were examined by meta-review. Our findings show that the "Second Life" platform has been frequently used in studies. Among the reviewed papers, case study designs and quasi-experimental studies were more common. Sample sizes were below 100 for most studies. 3D virtual learning environments are mainly designed for learning support, simulation, and game. Language learning and science have been the most extensively studied topics. Collaborative and exploration-based learning strategies have been used most frequently in 3D virtual learning environments. Presence, satisfaction, communication skills, and engagement were examined as emotional and cognitive achievements.

Keywords 3D virtual learning environment · Virtual worlds · 3D virtual environment · Comparative analysis

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Introduction

Three-dimensional (3D) virtual worlds are platforms that users can develop by applying their imaginations (Alarifi 2008). Avatars can represent the users' real presence (DeNoyelles and Seo 2012). Users can communicate via audio- or text-based tools (Dalgarno and Lee 2010; Dickey 2005). Numerous 3D learning environments have been developed using platforms such as Active Worlds, Second Life, On Live! Open-Sim, Traveler, Croquet, Adobe Atmosphere, and There (Hew and Cheung 2010). These platforms, first developed for the purposes of entertainment and gaming, are now also being used for educational purposes (Duncan et al. 2012; Wang et al. 2012). Such educational environments are called 3D virtual learning environments (3DVLE) (Zuiker 2012).

Virtual learning environments attracted remarkable interest around 2012 and that interest renewed by the rise of augmented reality applications combine virtual and physical world such as Pokémon Go and SoundPacman (Chatzidimitris et al. 2016; Serino et al. 2016; Piekarski and Thomas 2002). The affordances of 3D virtual worlds have a big part in the development of this situation. They permit users to design interactive environments with the content they want (Omale et al. 2009). They also make it possible to view a given problem from different perspectives and can include virtual activities that are difficult to practice safely in real life. Users are able to access virtual contents simultaneously, share information (Prasolova-Førland 2008), receive multifaceted feedback (Cheng and Wang 2011), and conduct activities by interacting with objects and individuals from online connection points in different locations (De Lucia et al. 2009; Sullivan et al. 2011). They are also important for the university policies that wish to fulfill the needs of individuals from different

places by allowing them to come together in virtual classroom environments and offering them a quality education and thus make use of rapidly progressing information and communications technology (Lee 2005; Phuong et al. 2015; Shah et al. 2011). Hence, leading universities around the globe have developed and implemented their own 3D virtual campus environments in instructional processes (Cheryan et al. 2011; Prasolova-Førland 2008).

Many researches were conducted to see effectiveness of those environments in terms of content type, teaching and learning approach, and learning outcomes. Meta-reviews provide a pre-filtered evidence to review and present the methodologically strongest data (Guyatt and Rennie 2002). Those studies reduce the time and expertise to locate the studies and subsequently appraise and synthesize them (Petticrew and Roberts 2006). Therefore, this study attempts to synthesize studies focusing on design and research issues in 3DVLE. This study, composes many of those research to see the trends and changes in 3DVLE research up to current times.

Learning design in 3DVLE

Like all instructional design processes, in designing virtual worlds, many issues must be considered. Understanding target groups (Franceschi et al. 2009; Eisenbeiss et al. 2012), selecting design platform (Dickey 2003), locating learning materials in accordance with design purpose (Fjeld et al. 2002; Karakus et al. 2016), and applying different learning strategies (Warburton 2009) are main issues while designing in virtual worlds. While virtual worlds have many affordances to support those issues, they have some barriers as well. A broad range of design approaches and learning contents does not mean that they provide a successful result. For example, those environments provide tools for collaborative learning but in some cases conducting a project without real meetings is not possible (Okutsu et al. 2013). Another example might be given for role-playing experience. Ho et al. (2009), in their study showed that role-playing approach was not well applied in virtual worlds since students had limitations to demonstrate their mimics and physical movements. Tendencies of design platforms and learning approaches might give a sense to suitability towards virtual worlds. A meta-review of those design issues might illuminate further virtual world design projects; in that it shows the tendencies of design.

Research in 3DVLEs

Virtual worlds with their flexible nature allow many types of research such as social, behavioral, and economic sciences and human-centered computer science. (Bainbridge 2007). Although they are available for more than two decades, they are still under development and this requires new research methodologies and new aspects. For example, virtual environment brought a new concept of social interaction and this needs to be further researched (Petrakou 2010). Virtual worlds in many cases are developed in scope of projects, and thus many types of research in different context were conducted under the projects (Clarke et al. 2006). Those research series generally start with a design-based research to exemplify the development process (Nelson et al. 2005; Clarke et al. 2006) and examination of the effects of the project (Ketelhut 2007; Nelson 2007) as in River City Project. Each study construct a step for the next generation of virtual worlds (Clarke et al. 2006). Therefore, tendencies of research interests, methodologies, different target learners, and context would be helpful to improve projects and reveal new research areas. Revealing those tendencies of research is an effort to create better research methodologies to invest in (Bainbridge 2007). For example, log files which hold user data are very difficult to analyze and come up with usable results (Feldon and Kafai 2008). Revealing those difficulties might lead new methodologies to analyze specialized data. Another example given by Hew and Cheung (2010) states that descriptive research is more popular comparing experimental research which might mean that creating an objective experimental design is not easy between real and virtual worlds. Thus, this might be a clue for in what ways experimental design is difficult as well. Therefore, this study reviews research methods and interests as a consequence of design issues.

Learning experience in 3DVLE

Virtual worlds are composed of many affordances of which researchers explore potentially appropriate pedagogies that could leverage these affordances (Girvan and Savage 2010). Collaborative tools (Minocha and Roberts 2008), virtual objects and environment (Dickey 2003), persistency of the world (Castronova 2008), and flexibility (Girvan and Savage 2010) might be listed as some of the affordances that support many learning types. Those learning dimensions might be cognitive, affective, or psychomotor (Hew and Cheung 2010). Collaborative tools and flexible environment might lead scientific inquiry and build higher-order skills in virtual communication and expression (Nelson et al. 2005). Avatar representation might be helpful to improve communication skills, while interacting virtual objects might provide a real-life experience (Dickey 2003; Duncan et al. 2012). Avatars, navigational, and socialization tools provide presence, which is positively associated with better learning outcomes for virtual worlds (Moreno and Mayer 2004) as new pedagogical approaches are integrated into virtual environments, the variety of learning outcomes increase as well. To persuade educators and

researchers working with virtual worlds requires showing best practices and results obtained in virtual worlds. Examination of negative and positive learning outcome examples in available research might give an idea about using different affordances to reveal the desired learning outcomes. Seeing the available learning outcomes in virtual worlds not only provide to associate them with affordances but also give a sense about effect of learner differences, contextual issues, design issues, and research issues on learning outcomes.

Reviewing virtual world studies

Steadily increasing the number of studies on 3DVLE has made the current body of literature unwieldy. Several partial reviews of which they focused on specific aspects of virtual worlds have been published already (Boulos et al. 2007; Richter et al. 2007; Hew and Cheung 2010; Inman et al. 2010; Lee and Kim 2010). Available studies usually concentrate on what kind of activities are performed in 3D virtual learning environments (Kim et al. 2012). Sivunen and Hakonen (2011) evaluated 47 3DVLE studies focusing on the phenomena of socialization and group methodologically and theoretically. Duncan et al. (2012) created a taxonomy to categorize individuals who use 3DVLE, the activities that are done in these environments, learning approaches that are used, supported technologies, and research areas. Kim et al. (2012) evaluated 65 studies focusing on K-12 and higher education in terms of the activities conducted, the methodology employed, the topics dealt with, and sample. Tokel and Karataş (2014) explored 55 3D virtual learning environment studies conducted between 2008 and 2013 in terms of cases, topics, disciplines, platforms, and participants. However, each of these studies has limitations, and their categorizations are general and lacking in detail.

There are a very limited number of studies which focus on the purposes for which 3D virtual learning environments are designed, the learning strategies used, and students' acquisitions in these environments. In addition, the fact that the number of the studies examined is small and do not pay attention to the negative effects likely to be posed by 3DVLE on students leads to a failure in making an extensive evaluation of the field (Kim et al. 2012; Tokel and Karataş 2014). Despite having studies categorized in terms of various metrics, the reviews did not consider whether the studies were applied or not. Moreover, the reviews often included a fairly limited number of studies falling below 50 studies per review. A new and more comprehensive meta-review of studies on 3DVLE is therefore needed. In the present study, considering the increased number of 3DVLE studies and emerging categories, a new approach to categorization was taken. By doing so, we were able to review more applied studies, include a wide range of categories available in some studies but not all, and add new categories such as learning strategies and student achievement. Therefore, a new and more comprehensive meta-review of studies on 3DVLE is needed to inform researchers on strategies used in 3D virtual learning environments, design goals, and target emotional and cognitive acquisitions which will help them understand the educational contributions of 3D virtual learning environments. The goal of this meta-review is to investigate empirical studies on 3D virtual environments in terms of their platforms, design goals, research topics, learning strategies, and findings. The research questions which guided this study are as follows:

In empirical studies on 3DVLE,

1. What were the trends in designing 3DVLE?
    a. What platforms were used?
    b. What were the sample sizes?
    c. How have the design goals of 3DVLE changed over time?
    d. What was the distribution of the used learning strategies in terms of design goals like?
2. What were the trends in 3DVLE research?
    a. What were their focal research topics?
    b. What research designs were used?
3. What results/student achievements were obtained?
    a. What were the positive and negative achievements related to emotional skills?
    b. What were the positive and negative experiences related to cognitive skills?

Methodology

Meta-review was the method used in this study. Meta-review method is used to build concepts from the data which are analyzed and coded (Glaser and Strauss 2009). In meta-review, categories are not assigned beforehand, but are developed via inductive analysis of the data. During the analysis process, the data are investigated individually; categories are created; these categories are then compared; relationships between them are examined; and finally, some categories are integrated or deleted according to the situation and new categories are sometimes created (Maykut and Morehouse 1994).

The scope of this study

To select studies for the meta-review, we chose articles which focused upon 3D virtual worlds. A search was

conducted in ERIC and Science Direct indexes. These databases were chosen because they were pioneer databases in the field of Educational Technologies. Articles related to River City and Quest Atlantis (which are well known projects) were included because these projects played a pioneering role in the proliferation of 3DVLE. To determine whether the studies were about 3D virtual worlds, a search was conducted for the following keywords: 3D virtual learning environment, 3D virtual environment, virtual environments, multi-user virtual environments, virtual, 3D VLE, and 3D virtual world. These keyword-identified studies were then checked for their methodologies to decide whether they were empirical or not. In this context, an empirical study refers to a study based on student data gathered from implementations where students were active participants of 3DVLE. In total, 167 articles were selected (see Appendix 1).

The data analysis

Firstly, the design platforms (i.e., Second Life, Active Worlds, etc.) used in the studies were examined. Following this, research design, research sample, the design goals of the 3DVLE, and the relevant research topics were recorded (Glaser and Strauss 2009). Categories were formed for each article, and then overlapping categories were united and those showing differences were presented separately. Frequencies were finally calculated and showed on the graph in these research areas for 167 studies. The most favored 4 design goals and their yearly distribution were plotted in the graph.

To identify the learning strategies used in the 3DVLE, categories were first developed based upon the five learning strategies (collaborative learning, situational learning, role-playing, problem-based learning, and creative learning) which Huang et al. (2010) suggested. Different learning approaches and methods used in the 3D virtual worlds were also investigated. The application of different learning approaches in 3D virtual learning environments was tabulated and graphed to allow a better investigation. The learning strategies used in the studies in relation to each design goal were also graphed.

Initially, it was intended to include psychomotor skills in the study as well. However, as the variables under this category were few in number and associated with emotional and cognitive domains, it was decided to give the acquisitions under two titles. To identify the students' positive and negative achievements with 3DVLE, their learning capacities were grouped into two main areas (Driscoll 2012; Senemoglu 2011): emotional (Krathwohl et al. 1964) and cognitive (Bloom et al. 1956). Main themes were then classified. Using meta-review, categories were developed gradually as the studies were examined (Senemoglu 2011), and overlapping categories were finally combined in a process similar to that used for the platforms, research designs, design goals, and research topics. The resulting categories were grouped together under two main themes for tabulation and calculation of the frequency values. Because more than one finding can be obtained in a single study, percentages for the findings are not included in our study.

Validity and reliability

To select only studies that dealt with 3D virtual worlds in an empirical fashion, keywords and methodologies used in the studies were examined. To ensure reliability, all of the 167 articles were investigated and categorized by one researcher. Then the constructed categories and the articles were reviewed by two researchers to eliminate the deficiencies in the categories. As a final step, these categories and articles were reviewed again by two other researchers to make sure that the reviewed articles and related categories matched correctly. To ensure the reliability of the coding between different researchers, inter-rater reliability kappa coefficient was calculated to be 0.88. Moreover, the Chi-square test of independence results indicated significant relationships between design goals and topics ($x^2_{(301)} = 431.85$, $p = 0.00$); between design goals and achieved emotional and cognitive acquisitions ($x^2_{(154)} = 200.80$, $p = 0.007$); and between design goals and employed strategies ($x^2_{(78)} = 100.96$, $p = 0.041$).

Findings

The trends in designing 3DVLE

Platforms used in the 3DVLE

The platforms used in the studies are presented in Fig. 1. However, two studies involved separate platforms for two different practices, and the platforms used were not mentioned in 24 studies. Hence, the obtained findings should be evaluated by keeping this in mind.

As seen in Fig. 1, various platforms were employed in the studies and Second Life was the most preferred one among them. The name of the platform employed to design was reported in 99 studies. Second Life was followed by Active Worlds (21) and Open-Sim (11) in terms of usage frequency (see Alsina-Jurnet et al. 2011; Bronack et al. 2006; Cheng and Ye 2010). On the other hand, 14% of the studies did not state the virtual learning platform and application employed. As Dalgarno et al. (2011) stated, SL and AW platforms support learning and pedagogy, which makes them more attractive for education. It is important for educational platforms to have features that facilitate

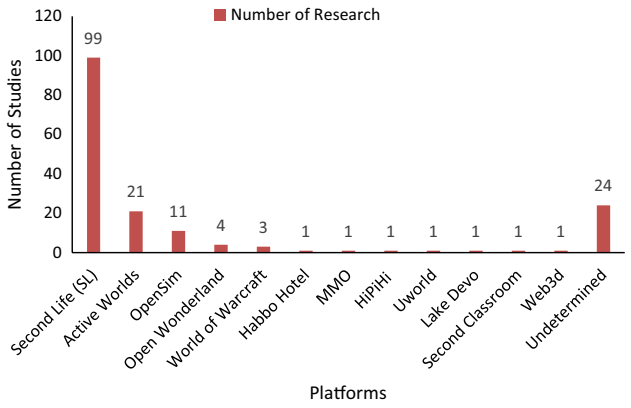


Fig. 1 The platforms or applications used in 3DVLE

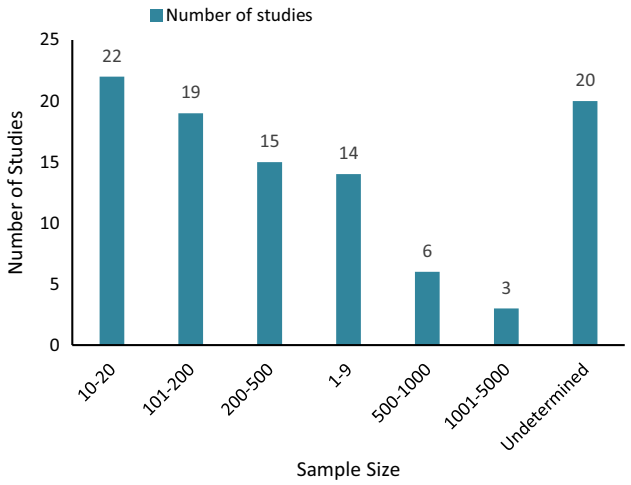


Fig. 2 The sample sizes used in 3DVLE

ready-made objects and personalization and support the use of various file types like video, music, and pictures (Messinger et al. 2009). They should also permit the creation of more interactive and attractive activities by adding codes to objects or avatars (Dickey 2005). Another important education-related feature of these platforms is that users creating identities for interaction in the environment must give their permission to be seen by other users (Dickey 2003).

Sample Size in the 3DVLE

The sample sizes in 3DVLE studies are presented in Fig. 2. Before evaluating the numbers, it should be noted that 20 of the studies did not report a sample size and one of the studies collected data from two distinct samples.

Figure 2 shows that majority of the studies employed sample sizes between 10 and 20 (n = 22), 21 and 50 (n = 37), and 51 and 100 (n = 32) (see Ferguson 2011; Jamaludin et al. 2009). The participants were mostly undergraduate students (n = 37); however, 96 studies did not provide any details regarding the participants. The participants' ages ranged from 18 to 80. For quantitative studies, the sample sizes might be assumed as low. These lower rates have resulted from the preference for case study and quasi-experimental designs, convenience of university students as participants, sufficient computer skill levels of university students, and infrastructure universities provide for efficient use of 3DVLE.

The changes in design goals of 3DVLE over time

Design goals of 3DVLE are presented in Table 1. However, three studies involved two different practices, and

Table 1 Design goals of 3DVLE

Design Goals	Definition	*f*	%
Learning support	An environment designed to support the development of various types of knowledge and student skills	41	24,55
Simulation environment	A modeling environment designed to simulate activities that are unlikely to happen in real life due to danger and expense	33	19,76
Social interaction environment	An environment used to communicate and interact with individuals living in different geographical regions or places	22	13,17
Game environment	An environment designed to allow individuals to learn and have fun while playing a game	21	12,57
Research environment	An environment designed to facilitate studies related to social and psychological factors (Test Anxiety Virtual Environments)	17	10,18
Environments for different learning strategies	An environment designed for the use of situated, inquiry, problem-based, collaborative, etc. learning strategies	13	7,78
Virtual Class and Campus	An environment designed to model one-to-one real learning environments in 3D platforms	11	6,59
Undetermined		9	5,39
Total		167	100

the used environments had different design goals. On the other hand, nine studies did not mention any design goal. In those studies, design platforms might be used as it was presented, for example, Second Life has many developed areas for socialization purposes.

The 3DVLE were mainly designed for learning support (43), simulations (33), social interaction (22), and gaming (21). These results prove that a wide variety of educational environments can be designed in 3D virtual worlds (see Billieux et al. 2013; Jamaludin et al. 2009; King et al. 2012; Wehner et al. 2011). The variety of 3DVLE supported by the ability to design realistic user experiences employing 3D media, interactions, avatars, the opportunity to alleviate time and place limitations, and the presence of verbal-auditory communication means. 3DVLE's ability to render impossible, costly, and even dangerous real-life events in a safe and cost-effective manner could be the reason behind this trend. Furthermore, designs aiming for social interaction could aid efforts to gather individuals from different areas together. In this study, 3DVLE designs were also investigated by year. Figure 3 presents the yearly distribution of the most preferred design goals.

The Fig. 3 shows that 3DVLE's are used for learning support almost every year. It is seen that the number of the 3DVLE's designed for learning support and simulation started to increase in 2010, reached the highest level in 2012, decreased in 2013, and remained stable in other years. It is obvious that the design of 3D virtual environments for gaming and social interaction varied between years. It is understood that the number of the designs for gaming reached the highest level in 2010, and the number of the designs for social interaction reached the highest level in 2012. It is clear that the studies mostly involved the designs of environments for learning support, simulation, and social interaction in 2014 and 2015.

The distribution of the used learning strategies in terms of design goals

The learning strategies used were not always mentioned in the studies. In 36 studies, more than one learning strategy was used. In Fig. 4, the learning strategies found in the studies are presented. Because more than one strategy was used in some studies, general total was not calculated.

Collaborative (45) and exploration-based (40) learning strategies were used in most of the studies (see Schiller et al. 2014; Zhang 2013). Role-playing (16), problem-based (13) were also used frequently (see Ibáñez et al. 2011; Lee 2013). To facilitate a problem-based learning strategy, 3DVLE help students to obtain, collect, analyze, synthesize, and evaluate information (Esteves et al. 2011; Sullivan et al. 2011). A 3D virtual learning environment which is designed to display a certain scenario helps students to develop strategies to solve problems by placing them virtually in a realistic situation where they must find a solution in a given situational context (Ibáñez et al. 2011; Schifter et al. 2012; Zuiker 2012). Moreover, the fact that 3D virtual learning environments allow communicating in text and voice communication environments by use of avatars and the gestures and facial expressions of avatars makes it easier for collaborative problem-based and role-based learning activities to be carried out (Tokel and Karatas 2014). In the present study, the strategies implemented for the most preferred design purposes were also investigated. Figure 5 presents the learning strategies employed in the studies by design goal.

The Fig. 5 shows that exploration-based learning strategy was preferred in game environments, collaborative learning strategy was preferred in simulation environments, collaborative and exploration-based learning strategies were preferred in learning support environments, and exploration-based learning strategy was preferred in social interaction environments the most. What matters in game environments is for students to confront with certain

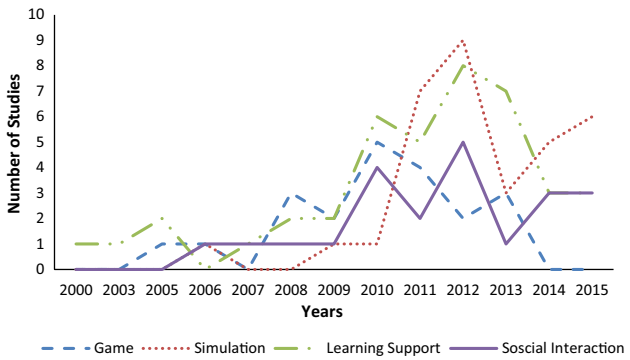


Fig. 3 The yearly distribution of the most preferred design goals

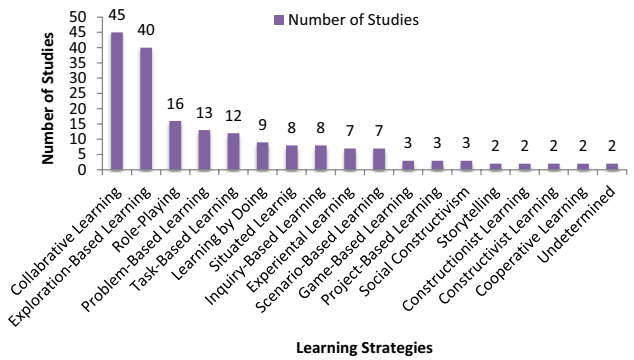


Fig. 4 The learning strategies used in the 3DVLE studies

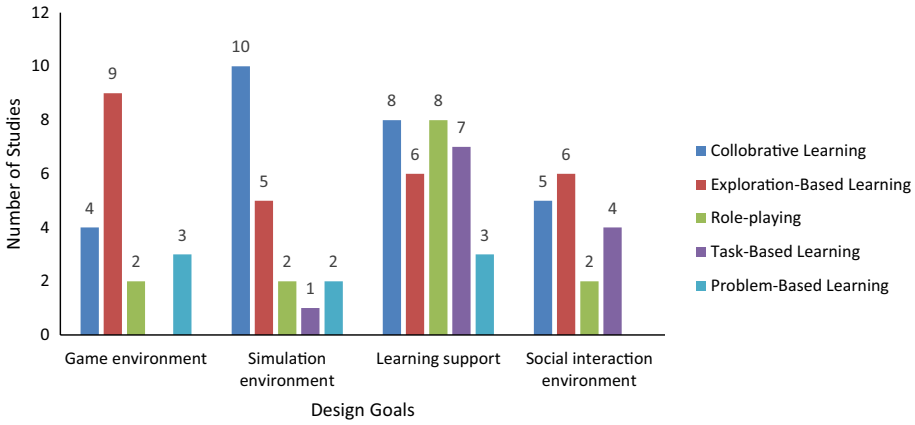


Fig. 5 The learning approaches employed by design goal

difficulties and to acquire knowledge by doing research in order to overcome these difficulties. This may be why exploration-based learning was preferred in designs of this sort most. The reason for preferring collaborative learning strategy in simulation environments most may be that individuals can solve the problems they encounter through collaboration in these environments just like in the case of River City.

The trends in 3DVLE research

Research topics in the 3DVLE

The research topics covered in the studies are presented in Fig. 6. However, 10 studies dealt with more than one topic, and 19 studies did not mention the topics addressed. As expressed previously, in some studies, 3DVLE's were used for collaborative purposes, therefore there might not be a topic of interest.

According to the Fig. 6, there were a very wide variety of topics covered. However, language learning (27), science (16), health science (14), and business (10) were the most common ones (see Erlandson et al. 2010; Henderson et al. 2012; Rogers 2011; Mathews et al. 2012). Ethics, culture, and winter sports (3) were among the least addressed topics. The fact that 3D virtual learning environments allow native and non-native speakers to communicate and collaborate within constructed scenarios independently of time and space may have caused weight to be given to language learning studies. The reason for the use of 3D virtual learning environments in health science may be that it allows students studying health science to acquire new knowledge and skills in 3D learning environments without harming themselves or patients (Boulos et al. 2007). Similarly, the reason to use 3DVLE in business education could be the chance to gain experience on probable issues in business life and develop strategies for dealing with them. The communication and interaction features offered by 3D virtual learning environments may have led to an increase in studies about science, in which problem-solving and inquiry.

Research designs used in the 3DVLE

The research designs used in the studies are presented in Fig. 7. Two of the articles reported two distinct studies utilizing different methods, therefore, they regard as two studies instead of one.

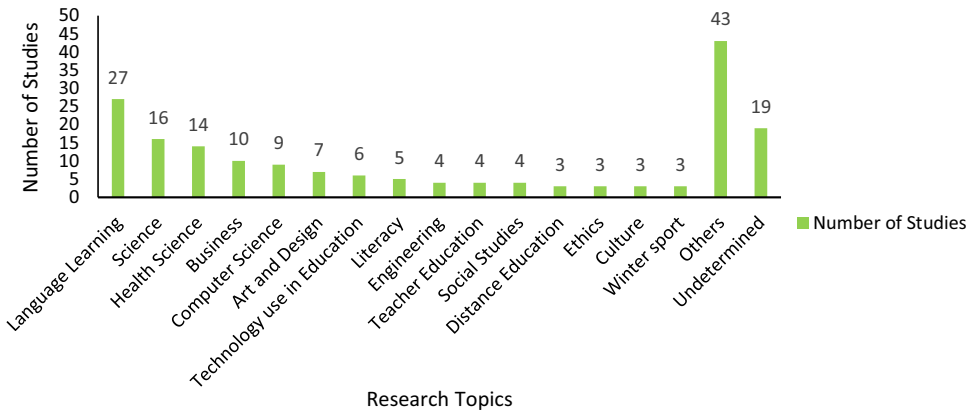


Fig. 6 The topics used in 3DVLE

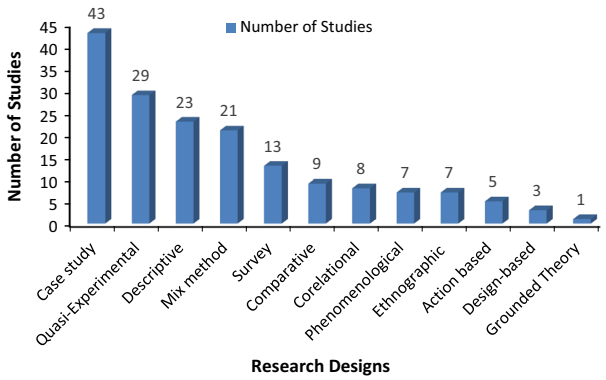


Fig. 7 The research designs used in 3DVLE

An investigation of Fig. 7 reveals that most of the studies preferred case study designs to examine a specific group or a situation in depth (n = 43) and quasi-experimental designs to compare different interventions applied to 3D learning environments (n = 29) (see Cheng and Ye 2010; Lorenzo et al. 2012). These research designs were followed by descriptive (n = 23), mixed methods (n = 21), and survey (n = 13) designs (see Bouta et al. 2012; Farahmand et al. 2013; Rico et al. 2011). In addition, few studies utilized action research (n = 5), design-based (n = 3) and grounded Theory (n = 1) research designs (see Ho et al. 2009; Warden et al. 2013). As to the type of data employed, the researchers preferred quantitative, qualitative, and mixed data sources in the order of preference. These results may have stemmed from the use of 3DVLE to (a) support participants learning on specific topics, (b) improve the quality of learning for the disabled, and (c) determine the effectiveness of 3DVLE in comparison to traditional, web-based, or 2D learning environments.

Results/student achievements were obtained

Students' positive and negative emotional achievements in 3DVLE

Figure 8 presents the negative and positive emotional achievements of students in the 3D virtual learning studies. Since 28 studies covered more than one emotional achievement and 89 studies did not cover any emotional achievement at all, the results should be interpreted with this respect.

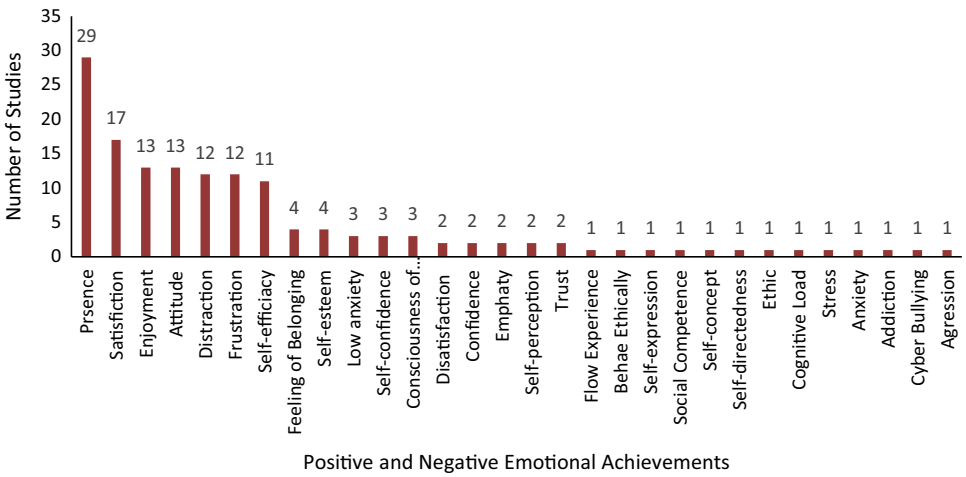
According to Fig. 8, presence (29), satisfaction (17), enjoyment (13), attitude (13), distraction (12), frustration (12), and self-efficacy (11) were the most common emotional achievements in the activities within the 3DVLE (see Bulu 2012; Kennedy-Clark 2011). Considering the findings, it appears that emotional responses triggered by 3DVLE features (e.g., interaction, continuity, sense of reality) were emphasized in the studies. Figure 9 presents the negative and positive cognitive achievements of students in the 3D virtual learning studies.

Figure 9 shows that communication skills (40), engagement (26), language learning (21), motivation (16), and perception (15) were considered as cognitive achievements in the studies (see Berns et al. 2013; Nadolny et al. 2013; Wehner et al. 2011). It also appears that the communication, realistic environment, continuity, and interactivity features of 3DVLE took priority when the researchers select cognitive achievements.

Discussions

In this meta-review, empirical studies on 3DVLE were examined in terms of their platforms, the design goals of the environments, research methods, research topics, sample size, learning strategies, emotional and cognitive

Fig. 8 Positive and negative emotional achievements in the 3DVLE studies



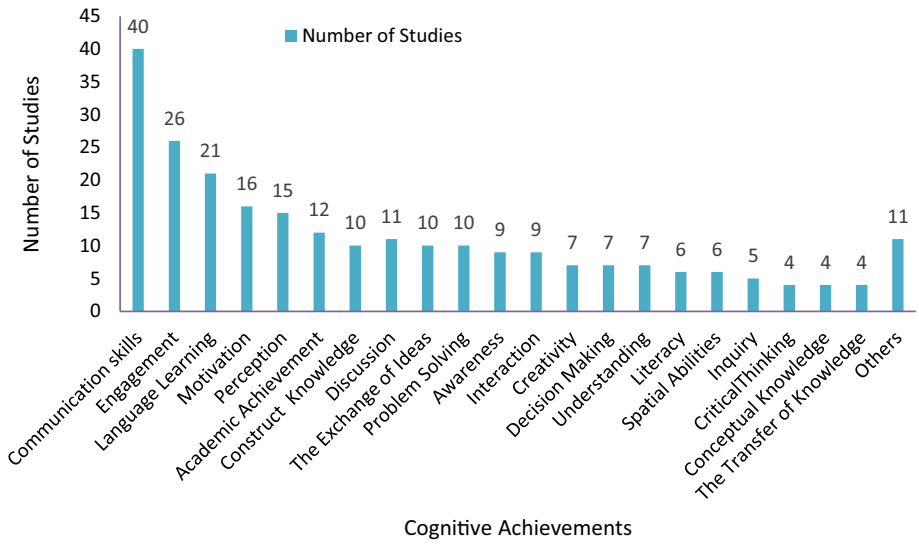


Fig. 9 Cognitive achievements in the 3DVLE studies

achievements, and negative experiences. This meta-review is limited by our selection of 167 empirical studies.

Second Life and Active Worlds were used as the platform in most of the studies that were investigated. A similar result was obtained by Tokel and Karatas (2014) and Kim et al. (2012), too. But interestingly, the Spring 2008 Eduserv report claimed that academics were not 'welded' to Second Life, "being aware of its deficiencies and open to moving to alternative virtual environments, especially open source and more localised versions" (Kirriemuir 2008, p. 2). This situation indicates that Second Life and Active Worlds could not totally fulfill the researchers' needs for security and cost-effectiveness and, therefore, have made them look for alternatives. This study focused specifically on empirical research studies in the field of education, and results should be evaluated in the given context.

Regarding the sample sizes, it has been found that a significant proportion of the studies employed samples up to 100 participants, with some exceptional studies utilizing samples of 1000 to 5000. In the literature, sample sizes reported to be within 0–835 range (Inman et al. 2010), and university students were the most frequently chosen participant group (Kim et al. 2012; Tokel and Karatas 2014).

The 3DVLE were generally designed as learning support, simulation, social interaction, and game environments. It was realized that the studies conducted in recent years have given weight to designs for learning support, simulation, and social interaction. Reviews and meta-reviews on 3DVLE pointed out common and probable applications of the medium. Kim et al. (2012) emphasize that 3D virtual learning environments involve different types of interactions and allow correctly simulating the real-life events. Furthermore, Tokel and Karatas (2014) state that 3D virtual learning environments can be used as e-learning, experiential learning, and social interaction environments; their use as experiential and social communication environments increased in 2011 and 2012. Hew and Cheung (2010) pointed out that 3DVLE are used for communication, simulation, and applications. According to Boulos et al. (2007), the fact that 3D virtual learning environments allow game-based learning activities is very important for education. As there is little published research on the design of learning spaces in 3D virtual worlds (Minocha and Reeves 2010), this summarization of the types of learning settings that might be designed in virtual world platforms should be useful to researchers and designers.

Collaborative, exploration-based were used most frequently in the reviewed studies. Likewise, Duncan et al. (2012) stated that collaborative, problem-based, and game-based learning strategies were used intensively in 3D virtual environments. Many other studies have shown that 3D virtual worlds are potentially very useful for collaborative learning (Bouta et al. 2012; Lorenzo et al. 2012). Richter et al. (2007) suggested that students can engage in performance, experiential, collaborative, constructivist, diagnostic, problem-based, role-playing, and skill development activities in 3DVLE.

Generally, the research topics that were most frequently seen in the 3D virtual learning environment studies were language learning, science, and health science. Previous reviews had also similar findings. Kim et al. (2012) highlight that 3D virtual learning environments are used for topics such as language learning, computer education, general education, science education, interdisciplinary education, economy education, and design education. Tokel and Karatas (2014) say that among the topics dealt with in 3D virtual learning environments are teacher education, language education, programming, medical education, librarianship, tourism, trade, and lifelong learning. Dalgarno et al. (2011) stated that arts and

humanities, information and computing technologies, and education are also topics often studied by use of virtual worlds. Hew and Cheung (2010) point out that topics regarding emotions, learning outcomes, and social interaction are commonly the focus of studies on 3DVLE.

The findings suggest that the 3DVLE researchers employed case study, quasi-experimental, and descriptive designs more frequently while very few of them preferred action-based, design-based, and grounded theory designs in their studies. Other reviews from the 3DVLE literature reported that the studies employed quantitative, qualitative, and mixed method approaches in the order of frequency (Inman et al. 2010), and that a majority of studies utilized experimental methods (Duncan et al. 2012; Kim et al. 2012). The present study extended those findings and brought about a broader perspective by reviewing a greater number of studies and study designs. As mentioned before, focus on the educational use of 3DVLE is a limiting factor of this study.

Students made achievements in emotional and cognitive areas in 3DVLE. Presence, satisfaction, enjoyment, attitude, distraction, frustration and self-efficacy were the main emotional achievements. Communication skills, engagement, and language learning, on the other hand, were the main cognitive skills. Tokel and Karatas (2014) point out that 3D virtual learning environments mostly involve the variables of attitude, learning, collaboration, presence, and identity. Duncan et al. (2012) marked that 3DVLE affect collaboration, experiential learning, analysis, evaluation, the construction of information, communication, and interaction in a positive way. Hew and Cheung (2010) indicated that 3DVLE affect students' awareness, academic success, learning of concepts, satisfaction, attitudes, and interaction positively, help students to develop their learning skills, and increase their perceptions of being in an environment and of belonging to a group. Wang and Lockee (2010) stress that the variables of collaboration and presence in the 3DVLE used in distance education are frequently discussed. The results identified in our meta-review are therefore similar to those found in the literature. As Hew and Cheung stated, all such results should be evaluated only after considering the methodology and data collection tools that were used, how long the subjects' practice lasted, and the validity and reliability measures of both the studies and their data collection tools. However, positive and negative effects distilled from the findings and conclusions sections of the respective studies because not all studies reported detailed accounts of effect sizes regarding cognitive and emotional achievements, and many studies included qualitative data. To gather more detailed information, investigating studies reporting effect sizes would be beneficial.

Conclusions and suggestions for future studies

Second Life and Active Worlds were the most frequently preferred virtual world platforms. So that, the use of Second Life and Active Worlds platforms may provide more flexibility and convenience for users and designers who want to design 3D virtual learning environments. In 3D virtual environments, the students, culture, technology, and pedagogy are all important (Wang et al. 2012). Further and more comprehensive analysis of these factors might make the jobs of teaching designers who use 3D virtual environments considerably easier. It also might be particularly helpful to further investigate the platforms that can be used, the students' needs, and the strategies that are most suitable to meet these needs while designing future studies. For many studies included in this review, sample sizes were below 100 and participants were university students. In the future, studies should employ larger samples of a variety of participant bodies such as pre-school children, the disabled, and adults. Common purposes for designing 3DVLE were learning support, simulation, and game-based learning. So, designers may easily design 3D virtual learning environments as learning support, simulation, and game environments. As to achievements, present was the most emphasized emotional achievement, while communication skills were the most frequent cognitive achievement. Including the development of high-order cognitive skills in 3D virtual learning environments may contribute to the field. Additionally, in-depth exploration of technical acquisitions in future research may contribute to a better evaluation of 3DVLE in terms of student acquisitions. The use of different data collection tools, especially in studies on higher-order cognitive skills, might help to reveal students' achievements more clearly.

Acknowledgements This study was conducted as part of the "Effects of Virtual and Multimedia Environments on Interest and Awareness Toward Winter Sports" project, supported by the Turkish Science and Technology Institution Project, number "111K516".

Appendix 1: The articles reviewed

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