

An Exploratory Research Agenda for 3-D Virtual Worlds as Collaborative Learning Ecosystems: Extracting Evidences from Literature

António Correia¹, Fernando Cassola¹, Diogo Azevedo¹, André Pinheiro¹, Leonel Morgado², Paulo Martins², Benjamim Fonseca², and Hugo Paredes²

¹ UTAD - University of Trás-os-Montes e Alto Douro, Dep. Engineering, Vila Real, Portugal.
Email: {ajcorreia1987,fernandocassola,diogosniker,andrepinheiro.infor}@gmail.com.

² INESC TEC/UTAD - University of Trás-os-Montes e Alto Douro, Dep. Engineering, Vila Real, Portugal.
Email: {leonelm,pmartins,benjaf,hparedes}@utad.pt.

Computer-supported online 3-D virtual world environments have been waxed and waned in interest and representativeness for supporting collaborative- and simulation-based practices. In a post-modern societal framework that requires inexpensive solutions for high-risk situations, research efforts in virtual worlds have developed a basis for understanding the use of virtual reality for multidisciplinary scenarios such as distance learning, training, therapy treatments, and social interaction. In this context, a recurrently updated research agenda for virtual worlds can characterize the current needs at a systematic way. This paper presents a meta-analysis of 35 publications to identify gaps and opportunities for research in collaborative three-dimensional environments based in content analysis. At a general perspective, there is a lack of established approaches to measure the influence and research potential of sociocultural factors in virtual worlds' usage, autism spectrum and other healthcare-related settings, learning outcomes, content characteristics, task support for groups and crowds, and online data collection.

Keywords: Bibliometrics, Collaborative Virtual Environments, 3-D CVE, Learning, Meta-analysis, Research Agenda, Second Life, Virtual Worlds.

1. Introductory remarks

Virtual worlds and metaverse platforms have appeared in literature as viable solutions for learning, working and other real-world simulation tasks, expecting a large and growing impact on teaching and learning in higher education for the near future (Hew & Cheung, 2010). Virtual world platforms have been adopted in a vast range of application fields such as healthcare, military training, economics, urban planning, architecture, education, or engineering (Jarmon et al. 2009). These hybrid virtual ecosystems provide an experience that transcends cultural, social, language, distance and temporal limitations through different modes of interaction (Anstadt et al. 2011).

Nevertheless, an integrated approach is needed to recognize how experiential collaborative activities can be enhanced using Collaborative Virtual Environments (CVE), in order to support the innovation processes imposed by the increasing competitiveness among organizations.

Synoptically, CVE provide different features to create an online presence that can simulate real-world settings, enable socialization through several communication channels, and support cooperative work (Jarmon et al. 2009) based in the possibility to communicate synchronously via chat or audio, coordinating actions and manipulating digital objects using shared applications. In this sense, team members can jointly look at and interact with digital artifacts in a shared virtual world (Schroeder et al. 2006). Studies in cooperative work using 3-D virtual environments identified some features for social interaction and sharing artifacts enhancing peripheral awareness (Bentley et al. 1992). However, there is a lack of ethnographical approaches to identify supported tasks and collaboration mechanisms used by groups and crowds.

With the advent of the new millennium, CVE presented a set of research challenges related with new kinds of human factors and needs, distributed architectures, scalability and interest management (Benford et al. 2001), taking lessons from Computer-Supported Cooperative Work (CSCW), 2D interfaces, and anthropological research. However, research needs are constantly changing and it becomes necessary the understanding of current working and learning activities in 3-D virtual environments to identify gaps and opportunities. In this perspective, bibliography can be a basis to identify a research agenda partially aware of technical innovations.

This study presents a meta-analysis for three-dimensional CVE focused on 35 journal papers, conference proceedings and technical reports, supported by a literature review using the guidelines of Kitchenham et al. (2009) to measure the current research possibilities. Bibliometrics (Price, 1963) is also applied as a method for measuring/analyzing scientific and technological literature. The contribution of this study is mainly sustained in an identification of the state of the art of a little portion of 3-D CVE literature, bringing a context

to new researchers that are taking the first steps in this field.

Section 2 presents some background of virtual worlds and its applicability for several purposes. Section 3 presents the method, selection criteria and sample dimensions. Section 4 presents a bibliometric perspective of the sample analyzed in this paper to measure literature characteristics. Section 5 shows codified evidences from review identifying research gaps in 3-D CVE. Finally, some final remarks are presented in section 6 based in qualitative and quantitative evidences identified from the literature review process.

2. Entering the ‘cave’: A brief exploration of three-dimensional CVE in a social era

Historically, CVE have been around since the early 90s, and some even before as ‘hardware-only systems’ (Joslin et al. 2004). These platforms included technical improvements such as simulators, stereoscope, ‘cinerama’, head-mounted displays and trackers (Grady, 1998). Some topics studied in the first decades included location and time dependencies, reality *vs.* virtuality, anonymity *vs.* true identity, human *vs.* technological factors, level and scale of immersion, play *vs.* work, and presence *vs.* telepresence. In this context, Jäkälä & Pekkola (2007) argued that the research efforts on virtual worlds have transited from “considering them as tools to examining their use, from technology engineering to social engineering”. While the focus relapsed on the technological aspects of 3-D CVE, there has been a need to understanding social interaction, comparing the magnitude of co-presence (Bailenson & Yee, 2008). A key purpose of “social virtual worlds” resides in the co-construction of a shared meaning through object handling, and communication with different people within a world (Damer, 2008). In a vast comparison between game- and social-oriented virtual worlds, Stangl et al. (2012) summarizes their success factors from scientific studies, pointing the support for a critical mass of residents as one of the several success factors attracting users.

A notable portion of the recent literature studies suggest that 3-D CVE can be well suited for experiential learning settings (Jarmon et al. 2009), military tactics and operations that require the latest innovations employing sophisticated technologies to prepare troops for a real combat (Pierzchała et al. 2011), mechanical processes related with maintenance tasks executed in military hangars (Fonseca et al. 2011), or healthcare-related approaches such as dentistry (Phillips & Berge, 2009), cardiopulmonary resuscitation (Creutzfeldt et al. 2010) or general medical learning (Wiecha et al. 2010).

In the context of higher education, researchers have been centered in the identification of requirements and potential benefits of project-based instruction and collaboration. In particular, researchers have found opportunities associated with social interaction, collaborative learning, an increased sense of shared presence, lowered social anxiety or partially liquefied social boundaries. In this sense, the

Collaborative Learning Environment with Virtual Reality (CLEV-R) was developed to enhance the afore-mentioned aspects (Jarmon et al. 2009). The benefits with the use of simulation tasks in this kind of 3-D virtual environments may range from cost saving to efficiency and security, and their amplification of sociability and scalability (Grimstead et al. 2005) can be far greater than of collaborative multi-user enabling systems.

Research in the K-12 and higher education suggests that interactions in three-dimensional CVE can stimulate users and produce conceptual understandings of the main subject matter (Jonassen, 2004), and the characteristics of this kind of virtual environments may promote collaboration to make the work more dynamic and engaging (Reeves et al. 2008). 3-D CVE have potential to support crowded online settings where hundreds of participants can reach social engagement by dynamically forming subgroups (Schneider et al. 2012).

Metaverses can be conceptualized as ‘immersive’ three-dimensional virtual worlds within which people can interact with software agents “using the metaphor of the real world but without its physical limitations” (Davis et al. 2009). The development of digital ecologies has been marked by media spaces, CVE, mixed reality and hybrid ecologies that merge the mixed reality with ubiquitous computing “to bridge the physical-digital divide” (Crabtree & Rodden, 2008). In this sense, 3-D CVE can be described as authentic collaboration ecosystems that minimize the risk of complex tasks through simulation features.

Virtual Interpersonal Touch (VIT) appears as a phenomenon in which people can interact synchronously via haptic devices with a virtual environment. However, psychological effects related to the haptic communication need research to explore this issue. The addition of a haptic tool in 3-D CVE where users can touch each other may increase co-presence (Bailenson & Yee, 2008), introducing a different ‘mode of immersion’ that can enhance spatial interaction between participants and objects.

In order to meet these evidences with an integrated view, a bibliographical review process gives a holistic perspective of literature production in the 3-D CVE domain, measuring bibliometrics from the scientific papers, unsolved gaps that claim for further research, and semantic metadata that can complement results with probabilistic correlations.

3. Method

A portion of CVE literature is studied using an evidence-based methodology (Kitchenham et al. 2009) to provide a synthesis of literature reviews, taxonomic studies, and other classification schemes related with 3-D CVE. This proposal relies on the identified need for recurring systematic studies to measure the evolution of topics, gaps, and opportunities for research in this field. Systematic literature review (SLR) is a method adopted by multiple domains (e.g.,

economics, software engineering, social policy, and nursing) to collect and review research results from other studies using a pre-defined set of search terms. The purpose of this paper is to identify a research agenda for 3-D CVE aware of its current status and needs. Specifically, we distillate journal papers, conference proceedings and technical reports that present a literature review, classification model, or research agenda.

3.1. Research questions

The formulation of Research Questions (RQ) respected a reflection process, stimulated by reading scientific papers in the field of 3-D CVE using the Google Scholar's advanced search to collect bibliographical data. The central question established in this paper relies on the definition of potential evidences about 'research gaps' recognized in bibliography, leading to the following RQ:

RQ1: What contributions can be provided by a systematic review about three-dimensional CVE?

RQ2: What are the unsolved gaps in 3-D CVE taking into account the existing literature reviews, taxonomic schemes, meta-analyses and research agendas?

RQ3: How to validate the achieved results and construct a reliable research agenda for three-dimensional CVE?

In order to answer these questions, this study is centered in a review of citable papers and technical reports to trace an integrated research agenda for 3-D CVE. In this context, we identified some contributions of a SLR in the following terms: i) provide qualitative data about the effects of a specific phenomenon across a vast set of settings and empirical methods (Kitchenham, 2004); ii) allow to combine research data using meta-analytic techniques (Kitchenham, 2004); or iii) allow to assess impacts and challenges of technological development and human interventions (Mallett et al. 2012). In the specific case of 3-D CVE, recurring updated agendas can bring perspectives about new collaboration features and requirements. However, there is a need for further research into the potential of SLR methodological approach.

Concerning the second question, a search by terms related with the identification of possible gaps in literature presents a possible solution, including only publications with this set of characteristics. With respect to the third question, results can be validated through scientific references using a 'snow ball' approach. Reliable sources can validate this research agenda, representing a point of departure for future agendas aware of innovations verified in the bibliography.

3.2. Search process

According to McGowan & Sampson (2005), systematic reviews and meta-analyses have a great importance to keep well-informed of literature implements and make informed decisions. Our review aims to identify evidences, selecting and classifying studies for possible inclusion, synthetizing results, and interpreting findings. To validate this approach,

we were involved into a bibliographic retrieval process with some complexity, organizing a specific amount of data and subsequent documentation, and restructuring the findings in a context of research agenda. The necessity for a systematic review of 3-D CVE relies on the summarization of existing data in literature, refining hypotheses and estimating sample dimensions to define a research agenda (Cook et al. 1997).

Table 1 represents an overview of the search criteria (C) adopted in the presented meta-analysis, establishing a set of keywords introduced in Google Scholar's advanced search to show a bibliometric perspective about scientific research in virtual worlds with emphasis on collaboration.

Table 1. Characteristics of the search process

Keywords and correlated terms	Search index	Criteria
K1: Collaborative Virtual Environments		C1: Journal papers, conference proceedings, and technical reports related with CVE in a virtual worlds' perspective
K2: CVE	Google Scholar advanced search to filter papers by	
K3: Virtual Worlds		C2: Systematic reviews, historical approaches, taxonomies, research agendas and classification models intended to classify virtual worlds
'AND'	citation number and subject matter	
CT1: Systematic review		
CT2: Taxonomy		
CT3: Classification scheme		

In the first stage, keywords (K) and correlated terms (CT) were introduced to retrieve a total number of 136 studies in accordance to bibliometric indicators (i.e., total number of citations) provided by Google Scholar's citation index. This process was complemented by a 'snow ball' methodological approach to identify potential related studies. The retrieved papers was reviewed according to their following sequence: i) keywords and general topic (defined from title), author(s) name, affiliation, country and additional identification data, ii) abstract, iii) full reading to identify possibilities and gaps and create an opening research agenda, and iv) bibliometric indicators (e.g., number of citations, topics, and countries).

3.3. Inclusion and exclusion criteria

The sample of the present study is a result of an inclusion/ exclusion process based in the guidelines of Sampson et al. (2003). Initially, a total of 136 papers and technical reports were retrieved taking into account the search terms showed in Table 1. In the next phase, three duplicated papers were removed. The lack of quantifiable metadata for two studies was also an exclusion criterion. Subsequently, a total of 46 papers were removed due to an inadequacy of their subjects for a meta-analysis focused in 3-D CVE and their unsolved gaps. Finally, a set of 50 papers were not analyzed in depth because they do not fit the second criteria (C2) represented in the Table 1. The remaining sample is constituted by a set of 35 publications associated with 3-D CVE that present an identifiable set of challenges and opportunities for research. From this analytical corpus, a wide range of studies related with learning (e.g., K-12, higher education) were identified.

A review of the resulting universe was made according to their bibliometric dimensions. Table 2 represents a basis for a research agenda partially aware of 3-D CVE requirements and shows the properties identified with the review process,

structured by reference data, country of author's affiliation, publication venue, citations, method, subject, and research possibilities (RP) identified through content analysis.

Table 2. Sample dimensions retrieved from literature

Author(s) and year	Country of author's affiliation	Publication venue	Total citations ¹	Method	Subject(s)	Research possibilities
Inman et al. (2010)	USA	Journal of Interactive Online Learning	20	Qualitative	Virtual Worlds, Education	[RP1]
Hew & Cheung (2010)	Singapore	British Journal of Educational Technology	65	Qualitative	Virtual Worlds, Education	[RP2]
Mikropoulos & Natsis (2011)	Greece	Computers & Education	33	Qualitative	Interactive Learning Environments, Education	[RP3]
Stanney et al. (1998)	USA	Presence	313	Qualitative	Human Factors, CVE	[RP4]
Parsons & Cobb (2011)	UK	European Journal of Special Needs Education	10	Qualitative	Autism Spectrum, Education, CVE	[RP5]
Bellani et al. (2011)	Italy	Epidemiology and Psychiatric Sciences	1	Qualitative	Autism Spectrum, CVE	[RP6]
Dalgarno et al. (2010)	Australia, USA	Australasian Journal of Educational Technology	14	Mixed Method	Virtual Worlds, Education	[RP7]
Zhou et al. (2008)	Singapore, New Zealand	IEEE International Symposium on Mixed Augmented Reality	132	Qualitative	Augmented Reality	[RP8]
Wright & Madey (2009)	USA	International Journal of Virtual Reality	6	Qualitative	CVE	[RP9]
Grimstead et al. (2005)	UK	IEEE International Symposium on Distributed Simulation and Real-Time Applications	28	Mixed Method	Collaborative Visualization Systems	[RP10]
Messinger et al. (2009a)	Canada, USA	Decision Support Systems	118	Mixed Method	Virtual Worlds, Business, Education	[RP11]
Messinger et al. (2009b)	Canada	Journal of Virtual Worlds Research	37	Qualitative	Virtual Worlds, Education, Business	[RP12]
Jäkälä & Pekkola (2007)	Finland	The DATA BASE for Advances in Information Systems	23	Qualitative	Virtual Worlds	[RP13]
Schmeil & Eppler (2008)	Switzerland	Journal of Universal Computer Science	21	Qualitative	CVE, Education	[RP14]
Olivier & Pinkwart (2007)	Germany	IfI Technical Report Series	1	Qualitative	CVE	[RP15]
Baladi et al. (2008)	USA	International Journal on Interactive Design and Manufacturing	3	Qualitative	CVE, Collaborative Design	[RP16]
Schmeil & Eppler (2010)	Switzerland	Facets of Virtual Environments	6	Qualitative	CVE	[RP17]
Otto et al. (2006)	UK	Virtual Reality Continuum and Its Applications	33	Qualitative	CVE	[RP18]
de Freitas (2008)	UK	JISC e-Learning Programme Report	85	Mixed Method	CVE, Education	[RP19]
Duncan et al. (2012)	Scotland, China	British Journal of Educational Technology	4	Mixed Method	Virtual Worlds, Education	[RP20]
Mennecke et al. (2011)	USA	Decision Sciences	8	Mixed Method	Virtual Worlds	[RP21]
Jarmon et al. (2009)	USA	Computers & Education	124	Qualitative	Virtual Worlds, Education	[RP22]
Bailenson & Yee (2008)	USA	Multimedia Tools and Applications	26	Mixed Method	CVE	[RP23]
Salmon (2009)	UK	British Journal of Educational Technology	75	Qualitative	Virtual Worlds, Education	[RP24]
Benford et al. (2001)	UK	Communications of the ACM	233	Qualitative	CVE	[RP25]
Davis et al. (2009)	USA	Journal of the Association for Information Systems	81	Qualitative	Virtual Worlds	[RP26]
Brown et al. (2011)	Australia	Business Process Management Journal	9	Qualitative	Virtual Worlds, Business	[RP27]
Joslin et al. (2004)	Switzerland	IEEE Communications Magazine	42	Mixed Method	CVE	[RP28]
Crabtree & Rodden (2008)	UK	Personal and Ubiquitous Computing	36	Qualitative	CVE, Ubiquitous Computing	[RP29]
Prasolova-Førland (2008)	Norway	Computers in Human Behavior	22	Qualitative	CVE, Education	[RP30]
Hasler et al. (2009)	Switzerland	International Conference on Human-Computer Interaction	6	Qualitative	CVE	[RP31]
Pinkwart & Olivier (2009)	Germany	Electronic Markets	4	Qualitative	CVE	[RP32]
Montoya et al. (2011)	USA	Decision Sciences	12	Mixed Method	CVE	[RP33]
Damer (2008)	USA	Journal of Virtual Worlds Research	21	Qualitative	Virtual Worlds	[RP34]
Wallace (2009)	USA	The International Journal of Technology, Knowledge and Society	0	Mixed Method	Virtual Worlds, Education	[RP35]

¹ Bibliometric indicators retrieved from Google Scholar's citation index in October 2012.

4. Bibliometric indicators of 3-D CVE research production

In the review scheme presented in Table 2, it can be seen a predominance of qualitative research studies followed by mixed method (qualitative and quantitative). The distinction between CVE and virtual worlds rely on the following criteria: i) at a CSCW perspective, CVE “represent a technology that may support some aspects of social interaction not readily accommodate by technologies such as audio and videoconferencing and shared desktop applications (Benford et al. 2001), encouraging peripheral awareness and ‘sharing artifacts’ (Bentley et al. 1992), and ii) virtual worlds can be seen as 3-D virtual environments that incorporate multi-use and immersive presence, inhabited by avatars and providing a ‘day-night context’ (Morgado, 2009). In this perspective, collaboration support tools such as Moodle and Facebook can be understood as CVE whilst Second Life is one of the most-known virtual worlds.

According to De Bellis (2009), bibliometrics can be established as a set of methods to analyze quantitatively scientific and technological literature. In this perspective, citation and content analysis are adopted as bibliometric methods to correlate a set of data aspects provided by literature. Figure 1 represents the number of studies reviewed in our study by author’s affiliation country. In this graphical representation, a greater scope from USA, UK and Switzerland was clearly identified. Although Australia does not show a major focus in our study, it is one of the countries with more studies in the current research scenario in virtual worlds. The results can point to the study of collaboration associated to virtual worlds by North American researchers as a practice of their work purposes. The total number of fourteen countries is a notable indicator that brings an intercultural approach to the 3-D CVE research from several universities geographically distributed around different continents.

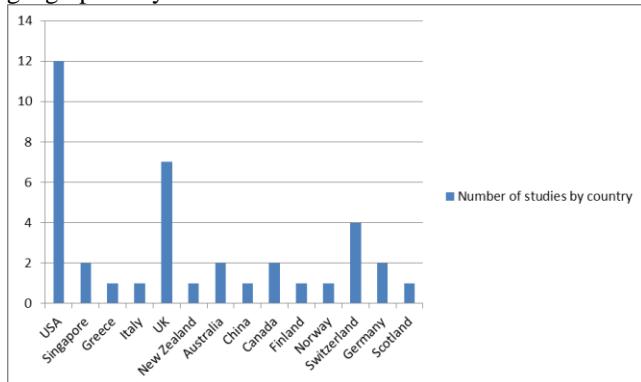


Figure 1: Number of reviewed studies by author’s affiliation country (1998-2012)

In the qualitative analysis represented in Figure 2, we can identify the related subjects for each study at a holistic way. CVE represent the main subject studied in our sample, and

it is followed by virtual worlds. Education is another field strongly examined in the recent years and in which there is a range of subareas to explore scientifically. Autism studies can be seen as a domain of notable importance to the future researches. Business remains as an interesting research field for CVE. Ubiquitous computing, Augmented Reality (AR), and collaborative design and visualization systems are other explored subjects. Finally, human factors are explored in a transversal way to the above-presented domains.

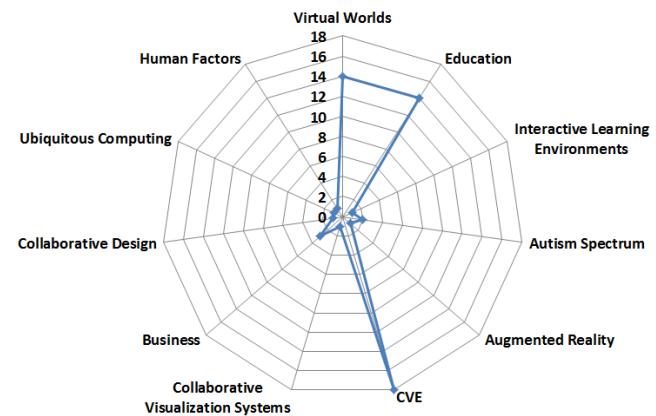


Figure 2: Subjects identified from review

Nevertheless, content analysis can be error prone due to the inherent human interpretation complexity. Limitations can be also established in the restrictiveness of the sample, which may not represent a large portion of current gaps and challenges of research in 3-D virtual environments taking in consideration the learning and working needs of society.

5. Towards a research agenda for three-dimensional CVE

It is time to reposition the state of research in the field of CVE to mobilize researchers, students and practitioners in order to achieve new goals and improve their capabilities to bring a context for complex tasks in learning, healthcare, working, or leisure. The codified research possibilities (RP) were based in a reading process focused on the aspects that provide an unexplored research topic, a set of guidelines to raise awareness on learning, cooperative work and human factors that claim for a compilation of fragments introduced in bibliography but without a scientific validation.

The research gaps and opportunities were achieved with a full-reading process, complemented with keyword search in the documents to obtain a new perspective about particular aspects. Some research notes were taken as a supplement to this bibliography-based analysis (e.g., sample size of review papers, and non-covered quotes). In this venue, we trace an overview of research gaps and possibilities for CVE (Table 3), extracting semantic evidences that can be suggestive for a more accurate meta-analysis with an extensive, granular, and flexible framework oriented to the current requirements of three-dimensional CVE.

Table 3. Codified data from review to identify research possibilities for 3-D CVE

Code	Description
RP1	<p>It may be time for researchers and educators to collaborate developing a more safe and secure environment for all students in K-12.</p> <p>Future studies may examine reasons why little research with K-12 education is taking place in virtual worlds (e.g., Second Life) when compared with higher education.</p>
RP2	<p>A field for further exploration would be the use of avatars in terms of androgyny, anthropomorphism, credibility, homophily and selection criteria during an interaction.</p> <p>There is a need for more research examining the unique attributes or affordances of virtual worlds.</p> <p>Future research is required to examine the influence of sociocultural factors and country contexts on the use of virtual worlds.</p>
RP3	<p>Few studies have incorporated intuitive interactivity and settings that use immersive virtual environments reporting positive results on users' attitudes and learning outcomes.</p> <p>Characteristics of virtual reality (e.g., immersion) and features such as the sense of presence (e.g., perceptual features, individual factors, content characteristics, and interpersonal, social and cultural contexts) seem to be essential for education and have not been studied extensively since 2003.</p>
RP4	Challenges related with human factors can be established into three primary fields within CVE: human performance efficiency, health and safety concerns, and social implications.
RP5	<p>We still need to understand how to use the features of virtual reality to best support learning.</p> <p>Questions about the nature of the representation itself remain unanswered.</p> <p>There is much potential in the use of virtual reality technologies for autism and other healthcare contexts, but this potential remains substantially under-explored in research terms.</p>
RP6	<p>The use of virtual reality tools for habilitation in autism is therefore very promising and may help caretakers and educators to enhance the daily life social behaviors of autists.</p> <p>Future research on virtual reality interventions should investigate how newly acquired skills are transferred to real world and whether virtual reality may impact on neural network sustaining social abilities.</p>
RP7	<p>The compilation of an annotated bibliography of published research into, and evaluations of, 3-D immersive virtual worlds in Australian and New Zealand higher education will provide a solid platform for further research that can be generalized to all countries.</p> <p>There is a need for an accurate picture of the 'state of play', including current, past and planned tools at various institutions, so as to help direct research, development and use.</p>
RP8	<p>Augmented reality technology creates opportunities for exploring new ways to interact between the physical and virtual world, which is a very important field for future research.</p> <p>Three research paradigms (i.e., ubiquitous computing, tangible bits, and sociological reasoning to problems of interaction) can be explored to create new interaction techniques.</p> <p>Projection-based displays can have an optimistic future.</p>
RP9	A possible study relies on the refinement of this evaluation in a different perspective (such as the classification of functional elements of CVE with a specific taxonomy).
RP10	Contributions can be suggestive with the expansion of publication spectrum to 2006-2012.
RP11	Attitudes and purchase intentions should be further examined so that companies can make decisions on the investment in their presence into virtual worlds and the marketing strategies most appropriate for their products (including co-creation and collaboration with consumers).
RP12	<p>Are standards of social behavior in virtual worlds evolving differently from those in the physical world? What social values? Norms? Do behaviors and attitudes learned in virtual worlds affect behaviors and attitudes in the real world? Should virtual worlds be regulated? Will laws and regulation influence creativity and productivity in virtual worlds?</p> <p>How does the nature of the platform influence people's behavior? Do synchronous and asynchronous forms of interaction differ in meeting people's information needs, stimulating social interaction, or engendering trust? Does the monetary system in virtual worlds influence behavior? How can virtual world platforms be used for virtual service delivery and Customer Relationship Management (CRM), electronic retailing, teaching, and libraries? What types of services, products or courses are most suitable? How should the appearance of an avatar sales agent or instructor be designed? Are different platforms more or less conducive to self-governance?</p> <p>For media placement, what are the demographics, psychographics, geographic characteristics, membership sizes, and participation levels of various virtual worlds? Do virtual worlds influence consumers' self-concept?</p> <p>Will virtual worlds support themselves with a single up-front fee, periodic subscription payments, advertising, pay-as-you-go extras, or sales of ancillary products?</p>
RP13	<p>A framework for studying and classifying individual users, virtual worlds, collaboration mechanisms and their relations can be proposed.</p> <p>Relevant themes and research items can be identified (e.g., by using qualitative methods such as Grounded Theory).</p>
RP14	<p>Further steps will include the definition of additional patterns, different classification approaches, and also the development of well-grounded guidelines for the creation of effective experiences for virtual environments.</p> <p>The current classification model is subject for on-going revisions, and scientific proof is still to be developed to help researchers, designers and practitioners to assess a 3-D collaboration and learning scenario in terms of its scope and benefits.</p> <p>Future work could include an experimental comparison of collaboration tasks in three-dimensional CVE against corresponding tasks in text-based CVE and real-life collaboration.</p> <p>To go deeper into collaboration, investigating the question of which theories help to explain 3-D interaction for collaboration and learning would be useful and interesting (e.g., the actor-network theory, Gibson's theory of affordances, and the cognitive scaffolding theory may be applied to 3-D environments).</p> <p>So far it is unclear what enhancements are needed to make a CVE a really useful environment for serious distributed collaborations.</p>
RP15	<p>Some research is still needed to fully understand the strengths and weaknesses of avatars in 3-D worlds in CSCW settings.</p> <p>Some possible research topics to explore are: (i) workplace adoption, which depends on how easy and useful do people perceive the CVE, (ii) success factors, related with the increased interactions, positive self-awareness and social bonds (trust), or are there other yet undiscovered factors?, and (iii) design elements can help to improve productivity in CSCW settings, the design factors – 'building blocks' – that led to the effect are not explored in depth yet.</p>
RP16	The taxonomy should be refined and expanded in accordance with the new issues that are continuously discovered.

RP17	This framework does not provide indications associated with the possible value added by collaboration patterns in virtual environments. Further research is needed through the use of controlled on-line experiments and in-situ participatory observation within organizations.
RP18	Until recently, supporting closely-coupled collaboration between remote people was considered to be very difficult to achieve. However, little is known about the influences of different factors on such collaboration. Many issues need still to be addressed, including an effective haptic implementation for immersive projection technology, as well as more research into the importance of gaze, facial expressions and body postures during concurrent object interaction.
RP19	It will be interesting to see how the license-fee based worlds will survive against the open source ones. The tension between participation, learner control, educational standards and quality assurance may provide a framework for ongoing work in this space, and accurate benchmarking metrics for evaluation and validation are still a primary goal. In the future, it is envisaged that multiplayer role play games and mirror worlds also will offer real opportunities for learning. A commitment towards participatory approaches at all levels of engagement seems a central requirement of future development, but we also need a commitment to ensure that the basic levels of education are maintained for future generations. Forthcoming functionalities may also include the ability for users to create their own content, using tools such as Sketchup and 3ds max.
RP20	There are several fields for potential research and development, such as appropriate educational activities, suitable learning environments, correct supporting technologies, revised learning theories, and experimental and verifiable evaluation practices for all population groups. There is a need for both finely grained categorical work and a holistic approach to research and practice in virtual education, encompassing multiple categories of the taxonomy. A more fine-grained research survey is recommended within 5 years to elicit trends and advances in this fast-moving field.
RP21	The current classification is subject to on-going revisions. Future research should focus on examining the research model to determine its validity, particularly for organizational applications such as product sales, organizational meetings, or informational briefings.
RP22	Future research would benefit from gathering data about the students' levels of technical ability in Second Life prior to the educational activity under study. While online 3-D virtual worlds are expected to have a large impact on teaching and learning in the near future, the understanding of their instructional use is still limited. With the use of virtual worlds, experiential learning opportunities can be vastly expanded. Some limitations include the fact that it represents a single case study, one graduate course and semester in length, and five graduate students from different academic disciplines. More research is needed to understand how experiential project-based collaborative activity may apply to other instructional contexts using Second Life.
RP23	It would also be interesting to study the effects of being touched in a virtual environment, while previous studies have explored mutual force-feedback, it would be interesting to study whether an agent that touched other would be perceived as more likeable in the same way that waiters get tipped more when they touch their customers. A task using avatars of different skin tones or ethnicities might reveal user's attitudes towards different racial groups. Future studies might employ instead a paradigm where the touch itself is social.
RP24	At present, Second Life offers the most powerful object creation toolset of any 3-D MUVE, and we need to contemplate many possible futures, engage in dialogue and undertake evaluation with different stakeholders about choices available to us. Awareness of teachers' visions about the potential of virtual worlds, especially in the teaching of history and science. Transfer of pedagogical concepts from other electronic environments to frame group development and group working. Creation of realistic environments for practice. Integration with other learning technologies with a view to creating 3-D virtual classrooms. Predictions of interest from commerce and industry for skills development.
RP25	Some of the various research challenges facing CVE are scalability (that will continue to be a core challenge for CVE) and interest management, distributed architectures, migrating lessons from 2-D interfaces and CSCW, as well as new kinds of human factors. The ever-expanding variety of multiplayer games and simulators demonstrates the potential of CVE in leisure and entertainment. How can we understand the nature of social interaction within a CVE? Ubiquitous, mobile, and wearable computing promises to make universal and continual access to digital information. A future research challenge concerns the relationship between the shared digital world, manifested through CVEs, and a shared physical world enhanced with digital information.
RP26	A research gap that needs to be filled relies on understanding how metaverses are different from traditional virtual collaboration and what theories are relevant for enhancing understanding of behavior, management, and technology phenomena in this environment. It is important to further investigate how teams balance in-world and out-world work, as well as what tasks are amenable to metaverse technology capabilities and what tasks are not.
RP27	The emergent themes of intuitiveness, ease of application, and enhanced knowledge sharing ability provide interesting conjectures that could be tested in further, more controlled, empirical research. Easy to use computer-supported networked collaborative process modeling is an emerging important challenge for the process modeling community. Future research can focus on the application of this approach in real-world collaborative process design scenarios to be able to evaluate efficacy and usability, and to examine potential benefits and changes to collaborative design processes carried out normally by business analysts. There is a need for usability analysis to be applied in the modeling interactions to improve their affordance for collaborative process tasks. A stream of research might want to examine the individual behaviors exhibited by analysts when working with the new approach to collaborative process modeling. There are opportunities for research on process modeling quality to examine the final outcomes of the collaborative modeling process, namely the process model produced, in terms of how well it corresponds to established quality notions such as soundness, usefulness, or user acceptance. Further extensions will be necessary to ensure scalability to larger and more complex process scenarios.

RP28	Most systems address forms to provide basic CVE platforms to users so that they can expand and develop more complex interaction methods addressed mainly by the use of component/plugin-based architectures (i.e., modular systems), and how to increase overall usage and make CVE platforms a standard rather than a specialty through the use of Java applications, PC-based software, and Web interfaces. This review can be expanded to a post-2003 analytical spectrum.
RP29	Understanding the nature of cooperative interaction within digital ecologies has been a longstanding concern within design and the emergence of a new class of interactive environment that spans the physical-digital divide warrants similar attention as computing moves away from the desktop and the workplace to disappear into the fabric of everyday life. Examining how novel interaction mechanisms are articulated across multiple physical and digital ecologies is essential to understanding the collaborative character of emerging physical-digital environments and, thereby, of informing design.
RP30	An important issue to consider during an analysis of CVE systems is to what extent other factors than the virtual place design influence their suitability in a concrete educational situation. How should three-dimensional educational CVE be designed to suit different educational purposes? What place metaphors are typically used? Which design features are beneficial and which are not? How could the virtual place design in such worlds be analyzed in a systematic way? The paper discusses the suitability of the adopted characterization framework as an analytical tool for future analysis of educational CVE, suggesting some revisions and additions.
RP31	A factor that has often been neglected in virtual team research is the physical environment from which team members access the virtual environment. A possible research agenda is focused on behavioral indicators of high- and low-performing teams, sociability factors and usability factors, toward a theoretical foundation for research on collaborative work in 3-D CVE. The authors believe that the automated behavioral tracking approach is an important step towards the systematic analysis of group interaction processes.
RP32	A future question relies on the possible classes of group work that can be enhanced through CVE. Where do the rich interaction options that they offer actually make a difference in practice? Recognizing gestures and facial expressions of the user and projecting them into the virtual world through the avatar needs to be advanced and the full potential of this interaction technique needs to be explored through ongoing CSCW research. The system requirements of many existing CVE (especially the non-gaming ones) are still beyond the standard office PC. Beyond basic HCI-related research and technological advancement, an open issue is concerned with the adoption of CVE in organizations, it is not generally clear what needs to be done for CVE to make inroads into the everyday work practices of users, probably one of the most crucial aspects to deal with it is privacy. There is a lack of systematic empirical research investigating the risks and chances of the new options that CVE technology offers within collaborative work contexts.
RP33	Given the social relational affordances offered by 3-D CVE, future research should examine the content of communications and the relationship with performance, for example, team transcripts could be content coded to reveal the proportion of communications devoted to task-related interactions (conveying ideas, decision making) and social/relational exchanges. Recent attention has turned to inter- and intra-organizational uses including collaborative virtual teamwork. There is a need for systematic and foundational research that examines the impact of 3-D CVE on team behaviors and ultimately performance-related outcomes. Further research is needed to gain a deeper understanding of the relative importance of affordances on both team processes and outcomes, particularly as they may vary by 3-D platform. There is a growing body of research on virtual teaming that examines how communication technology use is related with aspects of mediated team collaboration. Future research is needed to explore the learning curve associated with a 3-D CVE. From a practice perspective, this insight will help managers to understand what start-up costs will be needed to support a virtual team into a 3-D platform. Future longitudinal research engaging real teams in the context of real projects is required. Further empirical testing via both controlled experiments and field studies is necessary to gain a deeper understanding of these environments, what sets them apart, and how they can become valuable platforms for organizational teams.
RP34	Today, with the second coming of the avatar/social virtual worlds medium, predictably it is meetings and larger events from interviews on stage to fashion shows that are a driving force behind the growth and attraction to live in-world. There are emerging a large community of object makers, builders and marketers that can be monitored by researchers to trace a continuum of collaborative application fields.
RP35	While focusing on affiliateness and sociability is an interesting first step in the investigation of collaboration in virtual worlds for education, it is recommended that further research be undertaken to examine other personality traits related with collaboration in virtual worlds between avatars of different ethnicities, species and other forms, where further studies could examine such facets of personality as emotional empathy, arousal and sensation seeking, affect and emotions. In order to both understand and foster the sense of community, the development of positive social attitudes that participants in distance learning environments hold toward their classmates' avatars is an important field of research.

6. Concluding remarks

This paper represents an initial agenda with research gaps and possibilities related with 3-D CVE. Nevertheless, a set of limitations are established in the bibliometric level (e.g., limited sample in terms of size, restrictiveness, and lack of more papers from journals with a great impact factor), some methods, heuristics and interpretations of literature-based evidences are error prone, and there is a need to reinforce the creation of future agendas aware of technical and social requirements. Holistically, this meta-review shows that 3-D CVE find their place as alternative ecosystems to enhance learning and collaboration capabilities between humans and computerized residents and objects. There has been an incr-ease in the use of 3-D immersive virtual worlds in Australia and New Zealand. It is pointed that ubiquitous augmented reality has been arising, and ubiquitous tracking is on the track for future exploration. In a technical domain, Xj3D can be a platform well-suited to build and deploy 3-D CVE. The integration between CVE and CSCW application tools can increase user's self-awareness, improving social bonds between them and facilitating interaction and coordination. Additionally, this study needs future revisions and different perspectives on the current status of research in 3-D CVE, reinforcing a working line for several disciplines interested in the study of these collaboration support ecosystems.

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